A DECISION SUPPORT MODEL USING LIFE CYCLE COST (LCC) ANALYSIS TO SELECT COST-EFFECTIVE ALTERNATIVES FOR HAZARDOUS MATERIALS

THESIS

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of the Air Force Institute of Technology
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Table of Contents

Table of Contents (con't)

Table of Contents (con't)

Table of Contents (con't)

List of Tables

List of Figures

AFIT/GEE/ENV/93S-2

Abstract

This research focuses on the development of a decision support model to select cost-effective alternatives for hazardous materials using life cycle cost (LCC) analysis. The model provides an effective decision-making tool to evaluate the economic feasibility of using alternatives for hazardous materials.

Given a specific operation, the users of this model can enter site-specific cost data to determine the total LCCs of using baseline hazardous materials (i.e., hazardous materials currently being used in an operation), as well as the total LCCs of using various alternatives. This thesis postulates that the material having the lowest total LCC is considered to be the "best" alternative. In calculating the total LCC of a material, the following 12 LCC categories are evaluated: procurement, transportation, handling, facility, personal protection, medical, training, emergency response, monitoring, disposal, liability, and intangible cost.

This research also includes a case study of an Air Force operation (Pathology Lab Tissue Processing) to illustrate the use of the decision support model. Although the case study specifically addresses a single Air Force operation, the model can be applied to any operation that uses hazardous materials.

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I. Introduction

General Issue

The cost of managing hazardous materials has drastically increased in recent years due to the increase in the number of environmental and health regulations. Currently, organizations which use hazardous materials must comply with a myriad of federal, state, and local regulations. Each of these regulations imposes very stringent regulatory requirements which often translate into significant life cycle costs, including procurement, transportation, handling, monitoring, training, personal protection, medical, emergency response, disposal, and environmental liability cost (3:3-1; 4:2-1; 34:3). Since these requirements impose costs, the total Life Cycle Cost (LCC) of hazardous materials is the sum of the individual life cycle costs (LCCs) associated with the "cradle-to-grave" management of hazardous materials. All of these costs must be included to determine the true costs of managing hazardous materials. Since there are often different safety and regulatory requirements associated with different materials, the total LCC of alternatives for hazardous materials may vary considerably. Therefore, organizations which use hazardous materials must consider the total LCC of these materials in order to operate in a cost-effective manner. One of the methods that can be used to evaluate the cost-effectiveness of alternatives for hazardous materials is a concept called Life Cycle Cost Analysis.

Life Cycle Cost Analysis. LCC Analysis is a tool that can be used to determine the total LCC associated with a material, to evaluate the various alternatives, and to select the best alternative based on cost-effectiveness (21:1198; 38:3). LCC Analysis was first introduced about twenty-five years ago but only used to a limited extent (12:5; 17:1; 21:1197). It was first used by the federal government in procuring weapons systems (2:56). In the last few years, there has been a renewed interest in LCC analysis because of the increased costs associated with hazardous materials. For example, in 1986 the U.S. Air Force Scientific Advisory Board found that the LCCs of hazardous materials were not being adequately addressed in the selection of hazardous materials during the system acquisition process (34:5). To address this issue, the Air Force developed the Acquisition Management of Hazardous Materials (AMHM) Program.

Acquisition Management of Hazardous Materials Program (AMHM). The objective of the AMHM Program is to create an integrated oversight process to ensure that LCC considerations are given to hazardous materials during each step of the weapon systems acquisition process (48:1). This program is designed to evaluate hazardous materials to be used in weapon systems. However, it does not consider non-weapon system operations (i.e., Transportation, Supply, Civil Engineering, etc.) which are currently using hazardous materials. The Air Force's Pollution Prevention Program (PPP) addresses the use of hazardous materials in weapon systems, as well as in non-weapon systems operations.

Air Force Pollution Prevention Program (PPP). One of the requirements of the Air Force's PPP is to conduct base-wide Opportunity Assessments (OAs) once every three years to evaluate existing weapon systems and current operations including non-weapon system operations (15:4-16). These evaluations are designed to identify possible alternatives for processes which use hazardous materials. According to Air Force Directive 19-4, if hazardous materials cannot be eliminated, the Air Force must select hazardous materials based on life cycle cost analysis. In conducting these OAs, environmental and occupational health risks, as well as economic feasibility, must be considered to identify the best alternative for minimizing waste and reducing costs (15:3-9; 26:19).

One of the problems with the Air Force's PPP is that it provides very little guidance on how to evaluate the economic feasibility of various alternatives for hazardous materials based on LCC analysis. The Air Force's PPP manual simply states that a decision matrix should be used to evaluate and prioritize the various alternatives (15:3-9). In addition, base-level organizations currently do not possess the necessary tools to evaluate the LCC of using hazardous materials. As a result, these organizations are unable to conclusively evaluate the economic feasibility of the various alternatives when selecting alternatives for hazardous materials to be used in Air Force operations (26:1; 27:4,5; 32:1,2).

Problem Statement

The purpose of this study is to develop and test a decision support model using Life Cycle Cost Analysis to select cost-effective alternatives for hazardous materials used in current Air Force operations. This model will be designed to support the requirements of the Air Force Pollution Prevention Program.

Research Objectives

To achieve the purpose of this research, the following objectives have been established:

1. Determine the various cost categories associated with the management of hazardous materials.

2. Investigate various existing LCC models and determine if LCC analysis can be used to assess the total LCC associated with hazardous materials.

3. Develop a decision support model which can be used to select cost-effective hazardous materials.

4. Test the model in a case study using the data obtained from an actual Air Force operation.

<u>Scope/Limitations</u>

There are many potential uses for LCC analysis within the Air Force; however, this research concentrates on a single Air Force pollution prevention application: selecting cost-effective alternatives (hazardous or non-hazardous materials) for hazardous materials currently being used in Air Force operations (i.e., baseline hazardous materials).

The Air Force's Pollution Prevention Program includes a hierarchy to be used when addressing pollution prevention opportunities. There are five different levels within the hierarchy. The first hierarchial level is material substitution which includes the substitution of non-hazardous or less hazardous materials for hazardous materials currently being used. The next hierarchial levels include production/process changes, recycling, treatment, and disposal. This research only addresses the first hierarchial level (material substitution) and while it does not analyze other pollution prevention opportunities it can be combined with other heirarchial levels (e.g., process change and material substitution.)

The decision support model will be designed specifically for decision-makers at the operational level to evaluate hazardous materials used in weapon systems as well as non-weapon system operations. Lastly, this model will consider all present and future costs when evaluating the total LCC associated with a hazardous material from the initial purchase request until the material no longer imposes costs to the Air Force.

II. Background

Evolution of the Air Force's Acquisition Management of Hazardous Materials (AMHM) Program

In 1986, the USAF Scientific Advisory Board found that the LCCs of hazardous materials were not being adequately addressed in the selection of hazardous materials during the acquisition process (31:417; 35:5). Furthermore, the Scientific Advisory Board stated that the Air Force could significantly reduce the LCCs of hazardous materials through the better identification and selection of hazardous materials (13:1; 31:417). Based on these findings, the Scientific Advisory Board made the following recommendations:

- Ensure that the top level Air Force leadership integrate life cycle costs considerations in the weapon system acquisition process;
- Ensure that appropriate criteria and methods are developed to evaluate environmental and health considerations;
- Designate the System Program Office (SPO) as the focal point for exercising these considerations and making decisions for the selection of hazardous materials associated with weapon systems. (42:5-7)

In 1989, the Department of Defense (DOD) published DOD Directive 4210.15 which stated that its agencies must select, use, and manage hazardous materials over their life cycles to incur the lowest cost to protect human health and the environment (34:8). To comply with this directive, the Air Force drafted Air Force Regulation 19-17 which outlined the structure of the Acquisition Management of Hazardous Materials (AMHM) Program (34:9).

Current Hazardous Material Management Problems

In addition to the problems noted by the USAF Scientific Advisory Board, there are currently several other problems associated with the management of hazardous materials within the Air Force. For example, there are additional hazardous material management problems associated with the Air Force Supply System, the Air Force Pollution Prevention Program, and the Air Force Acquisition Process.

Supply System. Under the current supply system, the purchase price of hazardous materials is the only cost factor considered when selecting and acquiring hazardous materials. This is not a very cost-effective method in that it negates using total LCC analysis. For example, even though the purchase price of substitutes for hazardous materials may be more expensive, these substitutes may have a lower total LCC. Unfortunately, the current supply system does not consider the material's total LCC of when purchasing hazardous materials. Therefore, a decision support model that incorporates LCC Analysis would be very useful to the Air Force in terms of selecting cost-effective alternatives.

Pollution Prevention Program (PPP). As stated in Chapter I, the PPP manual provides users very little guidance on how to evaluate and prioritize various alternatives for hazardous materials, assuming that these alternatives are acceptable for use under current technical orders (TOs). Therefore, a standardized decision support model using LCC analysis would be very useful in terms of evaluating the various alternatives and thus supporting the goals of the Air Force PPP.

Acquisition Process. In addition to the findings already mentioned, the USAF Scientific Advisory Board identified several other problems with the Air Force's acquisition process. The board found that the System Program Offices (SPO), which currently manage the acquisition of Air Force weapon systems, are unable to accurately assess the financial impact of hazardous materials. In other words, the SPOs do not have the proper training and technical support to make the proper assessments of tradeoffs during the acquisition process (31:415; 42:8). To make sound decisions, the SPOs also need a method or tool to assess the effects of selecting various hazardous materials.

Air Force's Problem-Solving Approach

In an effort to solve the problems associated with the Air Force's acquisition process, the Air Force contracted the MITRE Corporation to conduct a preliminary study of the current hazardous material acquisition process and to make recommendations to reduce the cost of hazardous material management (35:1-1). Based on these recommendations, the

Air Force developed the Acquisition Management of Hazardous Materials (AMHM) program. The purpose of the AMHM program is:

> to institutionalize hazardous materials management within weapon systems acquisition, with the aim of designing out hazardous materials, and thereby minimizing hazardous material use and hazardous waste generation during all phases of the system life cycle. (34:1)

One of the goals of this program is to provide the SPOs with the necessary tools to make cost-effective choices based on the LCCs of hazardous materials. To meet this goal, the Air Force is providing the SPOs with the proper training and technical support and has developed a LCC model to evaluate hazardous materials at the research and developmental level (13:1). However, the usefulness of this model is limited because the cost data within the model is only applicable to certain Air Force weapon systems. This LCC model is designed to identify, track, and replace hazardous materials in specified weapon systems and allow weapon system managers to determine the costs of various hazardous materials that could be used in the system (17:413). These costs are divided into the following cost categories: "procurement, personal protection, management, handling, legal/environmental, medical, and disposal" (33:2.1-2.2).

The current AMHM program focuses on developing tools that can be used at the research and developmental level rather than at the operations' level (i.e., the level where the systems are actually used). In addition, the current program does not address the research and development of other types of Air Force systems (i.e., non-weapon systems). As a result, the Air Force may be using hazardous materials that are not cost-effective because the users of these materials do not have the necessary tools to evaluate various alternatives based on LCC analysis.

Life Cycle Cost Analysis Concept

Life Cycle Cost (LCC) Analysis considers all impacts and resources required throughout the life of a material. Therefore, LCC analysis can be a valuable tool for evaluating the environmental consequences or costs of a hazardous material across its entire life cycle. At every stage in a hazardous material's life cycle, the environment may be affected (e.g., through air emissions, ground water/surface water pollution, etc.) (17:1).

The LCCs associated with the management of hazardous materials are often very complex and are hard to quantify. For example, how do you quantify the environmental or liability costs associated with using hazardous materials in a maintenance process? In addition, there are myriads of costs that must be considered when attempting to evaluate the total LCC of hazardous materials. In the past, there have been several attempts to identify and evaluate these LCCs through LCC modeling. However, previous attempts consisted of LCC models that were too general (i.e., could not be applied to a specific operation) and, therefore, of little use to the actual users of these models (21:1197). This research seeks to overcome these barriers and provide decision-makers with a detailed and complete analysis tool to estimate the total LCCs of hazardous materials as well as non-hazardous materials.

Importance of LCC Analysis to the Air Force

As discussed earlier, the Air Force has recently realized the importance of LCC analysis in selecting cost effective alternatives for hazardous materials. The need for finding cost-effective alternatives for hazardous materials is mainly due to the recent increase in the number of regulatory requirements imposed by the Environmental Protection Agency (EPA) and Occupational Safety and Health Act (OSHA) Regulations. For instance, the latest amendments to the Clean Air Act are almost twenty times the length of the original Clean Air Act and impose many new regulatory requirements. An example of the increased requirements is the identification of an additional 175 hazardous air pollutants versus the 14 in the original act (20:73). In addition to new chemicals being regulated, other provisions within the act require organizations to spend money to install emission control devices and pay permit fees to operate processes that produces air pollution (20:73).

Consequently, the cost of managing hazardous materials increases significantly as new laws and regulations impose more restrictive management requirements. These compliance costs usually inflate expenses without providing any monetary returns on investments. As a result, proactive organizations choose to reduce their pollution more than the amount required by law (11:418). The most cost-effective way to reduce the costs associated with hazardous waste is to prevent its creation in the first place. Therefore, material substitution from a hazardous material to a non-hazardous material has the greatest potential to reduce costs. However, if hazardous materials cannot be eliminated, finding cost-effective alternatives (i.e., materials with the lowest total LCC) for hazardous materials can be a very effective method of reducing hazardous material management costs.

Although the Air Force is not a profit-making organization, it is concerned with obtaining the maximum benefit out of its budgeted monies. One of the tools that can be used by the Air Force to "stretch" its budget is to reduce the total LCC associated with the use of hazardous materials.

Conclusion

Due to the growing cost of managing hazardous materials, the users of hazardous materials must consider the total LCC of these materials in order to operate in a cost-effective manner. Finding cost-effective alternatives for hazardous materials is an effective method of reducing the total LCC associated with the management of hazardous materials. Therefore, LCC Analysis can be a valuable tool in determining the total LCC of hazardous materials and evaluating the cost-effectiveness of various alternatives. The Air Force has begun to realize the importance of LCC analysis in the acquisition management of hazardous materials. Currently, guidance on how to evaluate and select cost-effective alternatives for hazardous materials is very generalized and does not provide its users with the necessary tools for sound decision-making.

Additionally, the current Air Force guidance does not adequately address the cost-effective management of hazardous materials at the operations level (i.e., Base Supply System, Civil Engineering, etc.). The Air Force's main focus is on identifying cost-effective hazardous materials for weapon systems at the research and developmental level.

It is very important that the acquisition of hazardous materials be managed at the operational level as well as the research and development level. Also, the users at the operational level and the designers at the research and development level need the necessary tools to perform economic analysis of acceptable alternatives for hazardous materials. To address this problem, this thesis will suggest a decision support model to determine the LCCs of using alternatives for hazardous materials. With this model, the users of hazardous materials will be able to justify ordering a "more expensive" alternative, in terms of initial purchase price, by demonstrating that it is less costly over the entire life of the alternative. Therefore, a decision support model using LCC Analysis will be very useful to both the users of hazardous materials and the designers of Air Force systems in terms of selecting cost-effective alternatives.

III. Research Method

Introduction

This research will provide managers with a decision-making tool to evaluate the cost-effectiveness of using various alternatives for hazardous materials. The model will be developed and tested in four phases. During Phase I, the life cycle costs (LCCs) associated with the use of hazardous materials will be identified and categorized into appropriate cost categories. Phase II will investigate current LCC models to determine appropriate methods to quantify each cost category. In Phase III, a decision support model will be developed using economic analysis techniques. During Phase IV, the final phase of this research, the newly developed model will be tested in a case study using the data obtained from an actual Air Force operation.

Determination of Life Cycle Cost Categories (Phase I)

During this phase, the LCC categories will be determined to account for all costs associated with the "cradle-to-grave" management of hazardous materials. These costs will then be classified using a nominal scale. Next, existing LCC models will be examined to determine the various cost categories used in each model. Inconsistencies will be noted and support for differences will be established.

Investigation of Existing Life Cycle Cost Models (Phase II)

During this phase, various LCC models which are currently being used by private and governmental agencies will be investigated. This investigation will provide useful information to identify the various methodologies which can be used to quantify the total LCCs associated with the use of hazardous materials. Each of these methodologies will be evaluated to determine how well it quantifies the various cost categories identified during Phase I.

Development of a Decision Support Model (Phase III)

Using the information obtained in Phases I and II, a decision support model will be developed. Using the methodologies identified in Phase II, equations will be developed to quantify each cost category. In order to evaluate the cost-effectiveness of alternatives for hazardous materials, a consistent time value of money approach must be used. This model will evaluate alternatives for hazardous materials using present value analysis. The best alternative will be selected as the material with the lowest net present value.

Testing of the Decision Support Model (Phase IV)

The final phase of this research will involve a case study which will apply the decision support model to ensure that it can be used in the field. This case study will examine an Air Force operation and suggest acceptable alternatives for hazardous materials currently being used. To perform this case study, actual LCC data will be collected and evaluated to determine the total LCC of the baseline hazardous materials, as well as the various alternatives. This cost data will be collected using personal interviews and record analysis of historical records which will be obtained from the Environmental Management office, the Bioenvironmental Engineering office, and the operational workplace. Once collected, the data will be entered into the decision support model to determine the best alternative (i.e., the material with the lowest total LCC).

IV. Development of the Decision Support Model

Introduction

This research will provide decision-makers with a simple, easy-to-follow model to select cost-effective alternatives for hazardous materials. During the background study, four existing life cycle cost (LCC) models were identified. In developing the decision support model, the methodologies used in these four LCC models were evaluated to determine their feasibility in terms of selecting cost-effective alternatives for hazardous materials. The models identified in the background study included the Air Force's Hazardous Material Life Cycle Cost Estimator for Weapon Systems, the EPA Life Cycle Design Model, the Rankin and Mendelsohn Pollution Prevention Model, and the DOE's Waste Cost Analysis Model.

Model Reviews

AF Hazardous Material Life Cycle Cost Estimator (3)

Description of Model. The Air Force has recently developed the Hazardous Material Life Cycle Cost Estimator (HMLCCE) which is designed for System Program Offices (SPOs), contractors, and repair depot personnel to assess the cost of using hazardous materials in weapon systems (28:2-1). It evaluates hazardous materials' costs for all phases of a weapon system's life cycle. The Estimator currently contains cost data on three Air Force systems -- the F-16 fighter, B-1 Bomber, and aircraft engines (3:4-1).

Research is underway to conduct additional case studies to collect cost data on C-130 cargo aircraft and satellite launch vehicles (48:1). Since the Estimator is still in the growth stage, its application is limited to these types of Air Force systems.

Purpose of Model. The HMLCCE was designed to evaluate the cost of using hazardous materials in weapon systems and the processes that support these systems. This model will allow SPOs and their prime contractors to determine the cost-effectiveness of using less hazardous or non-hazardous materials. The ultimate goal of the HMLCCE is to provide the SPOs with a tool which will evaluate the total LCC of employing hazardous materials in weapon systems (3:1-2).

Methodology. Given a specific process, the HMLCCE will calculate the total LCC of using hazardous materials in a specific weapon system. The total LCC of hazardous materials is calculated using specific cost data collected during case studies of existing weapon systems. Using this data, the model can be used to estimate the cost of using a specific material in a particular process of a weapon system. These cost estimates are based on cost data which was collected in three case studies involving the F-16 fighter, B-1 Bomber, and aircraft engines.

LCC Categories. In developing this model, the following cost categories were identified as the primary cost drivers (28:2-2):

- Procurement
- Personal Protection
- Management
- Handling
- Potential Legal/Environmental Liability
- Medical
- Disposal

The procurement cost category includes the actual purchase price of the hazardous material plus the cost of transportation to the use site. The personal protection cost category consists of personal protection equipment cost, lost productivity due to wearing the personal protection equipment, and cost of dispensing the equipment. Handling cost is broken down into the cost of material segregation, labeling, distribution, and lost productivity due to these efforts. The potential legal/environmental liability cost category consists of the cost associated with toxic torts, regulatory authority correspondence, real property damage, contaminated water treatment, and natural resource damage. Management costs include the cost of maintaining oversight of the hazardous material at the use locations. The medical costs consist of the cost of physical examinations, medical surveillance, and industrial hygiene surveys. Lastly, disposal cost encompasses the cost of operating an Industrial Wastewater Treatment Plant, contractor disposal, and waste collection and analysis.

Evaluation of Model. In terms of evaluating various alternatives for hazardous materials used in Air Force systems currently available in the HMLCCE (i.e., F-16 fighter, B-1 Bomber, and aircraft engines), the model could prove to be very useful. Since the HMLCCE contains cost data which is directly applicable to these types of systems, the HMLCCE calculates the total LCC of hazardous materials using cost data which is often only applicable to these types of systems. Therefore, the users of this model cannot evaluate the cost-effectiveness of using alternative hazardous materials for other types of Air Force systems.

Since the total LCC of using hazardous materials is very site-specific and operation-specific, the usefulness of the model is limited. To improve the usefulness of this model, the users of this model must be able to enter site-specific and operation-specific cost data instead of using universal cost data which, in most cases, is only applicable to certain Air Force operations.

To overcome this limitation, this research effort will focus on developing a general decision support model which will be flexible enough to be used for any Air Force operation. This will include the capability to allow its users complete control over inputting cost data which is both site-specific and operation-specific. In developing this decision support model, some of the methodologies outlined in the HMLCCE were used; however, many of these methodologies had to be altered to fit the flexibility requirements of the new decision support model.

The HMLCCE also fails to consider the intangible costs associated with using hazardous materials. The decision support model will consider these costs, as well as additional cost elements, which are not considered in the HMLCCE.

EPA Life Cycle Design Model (18;19)

Description of the Model. This model was published in October 1989 by the Environmental Protection Agency (EPA) and revised in January of 1993. The model's main focus is on designing products over their entire life cycle as a means of reducing their LCC. In other words, the EPA's model evaluates the LCCs of a product from the acquisition of natural resources to the ultimate disposal of the finished product.

Purpose of Model. The purpose of this model is to provide its users with a management tool that will allow them to design products and manufacturing processes that will meet the following requirements: (1) protection of the environment, (2) product performance, (3) cost reduction, (4) cultural expectations, and (5) legal requirements.

Methodology. This model is broken up into several sections with each section addressing another way to balance the five requirements of a product. Some of these sections are:

- Product Life Extension Guidelines
- Recycling Guidelines
- Material Reformulating Ideas
- Process Management
- Transport and Packaging Guides
- Life Cycle Accounting

Each of these sections provides guidelines and suggested methods. The 1989 numerical model (19) was referenced by the 1993 EPA Life Cycle Design Guidance Manual (18). The users of this model must obtain both publications to perform an analysis.

Cost Categories. Under the Life Cycle Accounting section of the model, the costs are divided into Usual, Hidden, Liability, and Less Tangible Costs. Under each of these cost categories, examples of the particular type of costs are given. Specific equations are also provided in the October 1989 model.

Shortcomings/Benefits of the Model. Even though the model does not specifically address the LCCs of hazardous materials, it is an excellent source of information. Since the Air Force is primarily concerned with providing services rather than producing products, the usefulness of this model is limited in terms of this research. Even with this limitation, there were sections of the model that were useful in terms of evaluating the LCC of hazardous materials (i.e., equations for evaluating liability costs). The example cost areas provided within each major cost category (i.e., usual, hidden, liability, and less tangible) are also helpful in ensuring that all of the LCCs associated with hazardous materials are included in our model.

The Rankin and Mendelsohn Pollution Prevention Model

Description of Model. This model was developed as an Air Force Institute of Technology Masters' Thesis (32). The model identifies cost categories that are present in activities that generate pollution. Equations are written for each cost category and example calculations are provided. A systematic method is outlined to determine the costs and benefits of a proposed pollution prevention alternative.

Purpose of Model. The purpose of this model is to provide Air Force managers with "simple, systematic, and flexible guidelines for decision-making involving pollution prevention alternatives" (32:4-1).

Methodology. The model first describes how the different types of cost-benefit evaluation techniques work. One of the techniques discussed, Net Present Cost, will be used in our model. Next, they develop the heart of their model, the Pollution Prevention Investment Decision Model (PPIDM) Equations. They use a three-level technique to evaluate a pollution prevention alternative (32: 4-9,4-19). Each level of analysis involves a different set of cost categories. The level one cost categories which are intangible costs are not evaluated in terms of their actual cost because they cannot be quantified. Instead, they are used to determine the economic feasibility criteria that will be required for the next two levels. Starting with level two (tangible costs), the costs for these categories are determined, and a net present cost is calculated. If there is a "clear choice" as to which pollution prevention modification should be made after this analysis, then the process stops. If there is no "clear choice," then a third set of cost categories is analyzed; and the cost savings are added together from both levels. At this point, a decision must be made as to whether the pollution prevention project should be implemented or canceled (32:5-2).

Cost Categories. The cost categories are divided into three levels. Level One includes those cost categories that are intangible. Levels Two and Three contain cost categories that contain primary and secondary tangibles respectively. Some of the cost categories in each level that are particularly useful in this model are listed in Table 1.

Shortcomings/Benefits of Model. The Rankin-Mendelsohn model also contained many cost categories that were used in other models as well. These other categories have also proven useful and have been incorporated in our LCC model. The Rankin-Mendelsohn Model demonstrates a good method to determine the expected cost of a less tangible cost category using probabilities. The primary reason that this model was not sufficient for our use was that it did not include all of the cost categories that are involved in the total life cycle of a hazardous material in an Air Force operation.

Table 1

Cost Categories Used from Rankin Model
(32:4-9)

Intangibles (Level One)	Primary Tangibles (Level Two)	Secondary Tangible (Level Three)
Improved Public Image	Pollution Management	Health Hazards
Avoided Bad Press	— Air Control equipment	— Medical Time off Work
Improved Employee Attitudes		Regulatory Fines and Penalties

Department of Energy (DOE) Waste Cost Analysis Model

Description of Model. The Savannah River Site (SRS), along with other Westinghouse GOCO sites, have recently developed a generic model for calculating the life cycle costs (LCCs) of various types of DOE waste including sanitary waste, low-level radioactive waste, intermediate-level radioactive waste, transuranic waste, hazardous waste, and mixed waste (25:6). This model presents site-specific methodologies and guidelines for quantifying each waste's LCC. The DOE designed this model to allow its users to evaluate the economic impacts of various waste management options using a consistent decision-making approach.

Purpose of Model. Waste costs are a significant factor to consider in manufacturing and service operations and are becoming a primary management issue (25:2). Sound decision-making requires a comprehensive analysis of the LCCs associated with managing wastes. This model was developed to enhance the DOE facilities' ability to make sound and informed decisions concerning waste minimization options and waste generation activities. The current uses of the DOE's Waste Cost Analysis Model include:

- evaluate options developed during Process Waste Assessments,
- define and enhance priorities of waste minimization activities,
- evaluate cost savings associated with a waste reduction program or activity,
- evaluate the cost/benefit of a modification to a waste generating process,
- establish a current cost for the waste processing that allows for the economic evaluation of proposed changes to the life cycle of a waste,
- provide comparable cost for similar activities performed by different organizations which may be used to evaluate an organization's effectiveness (25:1).

Methodology. For this model, costs are classified according to whether they are fixed cost, variable cost, or sunk cost. For example, the following formula is used to calculate the total LCC of hazardous waste: (24:2)

$$\textit{Total LCC Cost} = \textit{Fixed Cost} + \textit{Variable Cost} + \textit{Sunk Cost}$$

The fixed costs are independent of the amount of waste generated and remain constant regardless of throughput. An example of a fixed cost is facility overhead costs that must be present regardless of the amount of waste generated. Variable costs are those costs that vary directly to changes in the level of activity or, in this case, the amount of waste generated. Therefore, variable costs are usually reported using a per unit basis. Examples of variable costs include transportation costs and waste disposal costs. The sunk costs are costs that have already been incurred, committed, or planned and do not impact current or future waste generation. Examples of sunk costs are the costs of existing facilities and the capital committed to manage wastes currently being generated. These costs are normally not included in the calculation of the total LCC because they do not affect today's business decision; therefore, the DOE Model does not calculate sunk costs (25:5).

LCC Categories. Based on the methodology used to construct this model, the LCCs of hazardous materials can be categorized into the following five major cost categories:

- generator costs
- transportation costs
- waste management costs
- closure costs
- monitoring costs

According to the model, each of these categories can then be broken into fixed, variable, or sunk costs. Generator costs identified in the model include costs such as manpower costs to obtain, fill, close, monitor and transport hazardous waste drums at the generation point. Transportation costs include the manpower and equipment costs to transport the hazardous waste from the generation point to the storage facility. Waste management costs include operating and support costs, storage costs, treatment costs and burial costs for hazardous waste retained on-site. Closure cost is the estimated cost for the closure of a hazardous waste burial site. Monitoring costs include the costs associated with the monitoring and surveillance of a hazardous waste burial site (25:30,31).

Evaluation of Model. In terms of evaluating and calculating the total LCC of the various types of wastes which are unique to the DOE, this model could prove to be very useful. However, in terms of this research, this particular model, as a whole, is not appropriate due to differences in operations and the types of waste generated within the Air Force. For example, much of the cost data and assumptions used in the development of the DOE's model are concerned primarily with radioactive waste and apply specifically to DOE facilities. On the other hand, the Air Force generates a much wider array of waste types; radioactive waste comprises a relatively small portion of the total waste generated.

In addition, the DOE's model considers only those costs associated with the management of wastes. In other words, waste costs start when a material is declared a waste. Therefore, the various costs associated with the management of the material (i.e., medical costs, personal protection costs, etc.) before it becomes a waste are not included in this model. This model also fails to address social and environmental costs. These costs are considered intangible costs for purposes of this model.

Even though the model as a whole could not be used to evaluate the LCCs of hazardous materials used within the Air Force, some of the methodologies used to evaluate the various LCCs proved to be useful in the development of the decision support model.

Development of the Decision Support Model

None of the previously discussed models had all of the necessary components to meet the specific needs of this research. Because of this, a new decision support model will be developed specifically to meet the needs of this research. In developing the decision support model, determination of life cycle cost categories (Phase I) and the analysis of existing life cycle cost models (Phase II) were performed concurrently. The end result is a listing of Air Force-specific cost categories that encompass the "cradle-to-grave" management of hazardous materials. These cost categories are listed in Table 2.

Table 2

Life Cycle Cost Categories

• Procurement	• Handling	• Emergency Response
• Transportation	• Personal Protection	• Disposal
• Facility	• Monitoring	• Liability
• Training	• Medical	• Intangible

Assumptions. The life cycle of a material begins with the purchase of the hazardous material by the Air Force. Therefore, this model does not consider the costs associated with the production of the hazardous material since these costs are not incurred by the Air Force. Cost or cash outflows are considered positive values. Benefits or cash inflows are considered negative values. All alternatives considered must result in the same or better performance as when using the baseline (i.e., current) hazardous material.

Overview of the Decision Support Model

The step-by-step procedures to evaluate the economic feasibility of alternatives for hazardous materials are as follows:

Step 1. For the chosen operation, determine the baseline (i.e., current) hazardous materials being used. The Bioenvironmental Engineering Office (BEE) can assist in determining which operations use hazardous materials and which materials within those operations are considered hazardous.

<u>Step 2</u>. Determine if any alternative materials are available as substitutes for the hazardous materials currently being used in the operation. These alternative materials can be identified through a review of the Technical Orders, during Pollution Prevention Audits, from the BEE Office, from inquiries to other bases performing similar operations, and from technical journals and other publications.

<u>Step 3</u>. Select one of the baseline hazardous materials identified in step 1 and one of the alternatives identified in step 2. The later selection can be any of the possible alternatives identified in the previous step.

<u>Step 4</u>. Estimate an appropriate life cycle (number of years) to be evaluated. The selected life cycle for evaluation should be the same for both the baseline hazardous material and the selected alternative. The appropriate life cycle should extend into the future a sufficient length of time to account for all of the costs that will occur due to the use of the materials. However, it should be noted that increasing the life cycle increases the uncertainty of the cost factors involved. To minimize these uncertainties, the life cycle should be selected with care.

<u>Step 5</u>. Evaluate each of the LCC categories listed in Table 2 and discussed later in this chapter to determine

which cost categories will have a monetary change as a result of the substitution of the selected alternate material. Changes may occur in a cost category due to actual monetary differences (e.g., differences in the cost of a particular cost category) or from differences in the time frame that the costs are incurred (e.g., costs incurred at different times). Many of the cost categories will not change as a result of the substitution. These categories do not need to be calculated to determine the economic feasibility of the substitute.

Step 6. For each cost category, except intangible costs, identified as being different in either of the two ways described in step 5, calculate the annual cost using the equations outlined at the end of this chapter for the baseline material and the substitute material over their entire life cycles.

Step 7. Calculate the total annual cost (i.e., sum of the individual cost categories) for the baseline material and the substitute material over their entire life cycles.

Step 8. Inflate each of the total annual costs calculated in step 7 using the inflation tables, provided in Appendix A, over the selected life cycle. Next, calculate the Net Present Value of the baseline hazardous material and the substitute material using present value analysis. (see Appendix B for a discussion of Present Value Analysis)

Step 9. Repeat steps 3 through 8 to evaluate the economic feasibility of other possible alternatives.

Step 10. If the Net Present Value for all of the alternatives is greater than the baseline material, then continue to use the baseline material.

Step 11. Select the alternative which results in the greatest cost savings (i.e., the smallest Net Present Value). If any of the alternatives are "close" in terms of the Net Present Value, then intangible costs of the alternatives should be considered in determining the best (most cost-effective) alternative.

Step 12. If the user needs to evaluate another baseline material, he or she should return to Step 3. If the user does not need to evaluate another material, the evaluation is complete.

Figure 1 is a flowchart of the Decision Support Model. This flowchart can be used to aid the user in following all the steps discussed in the paragraphs above.

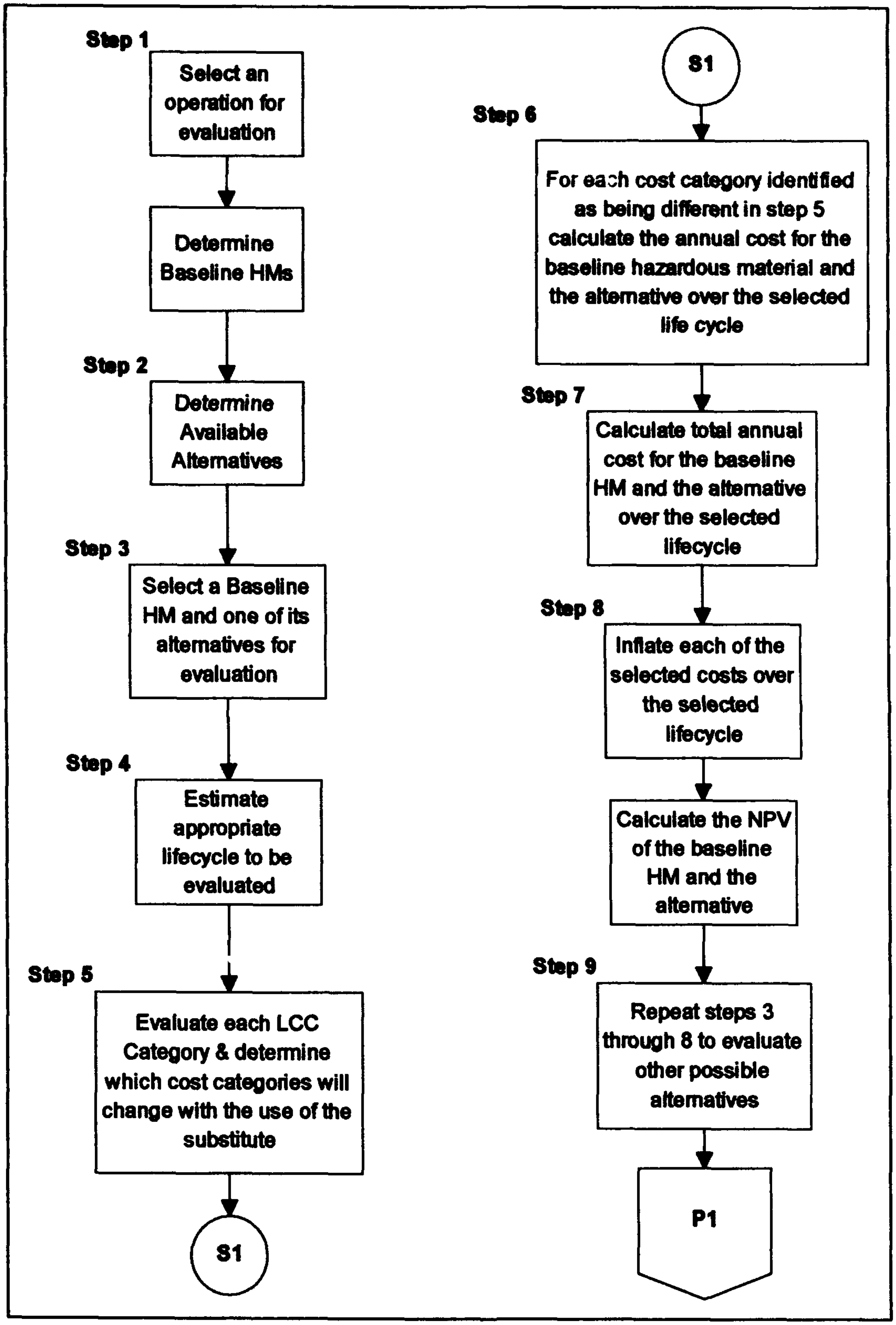

Figure 1. Decision Support Model Flowchart

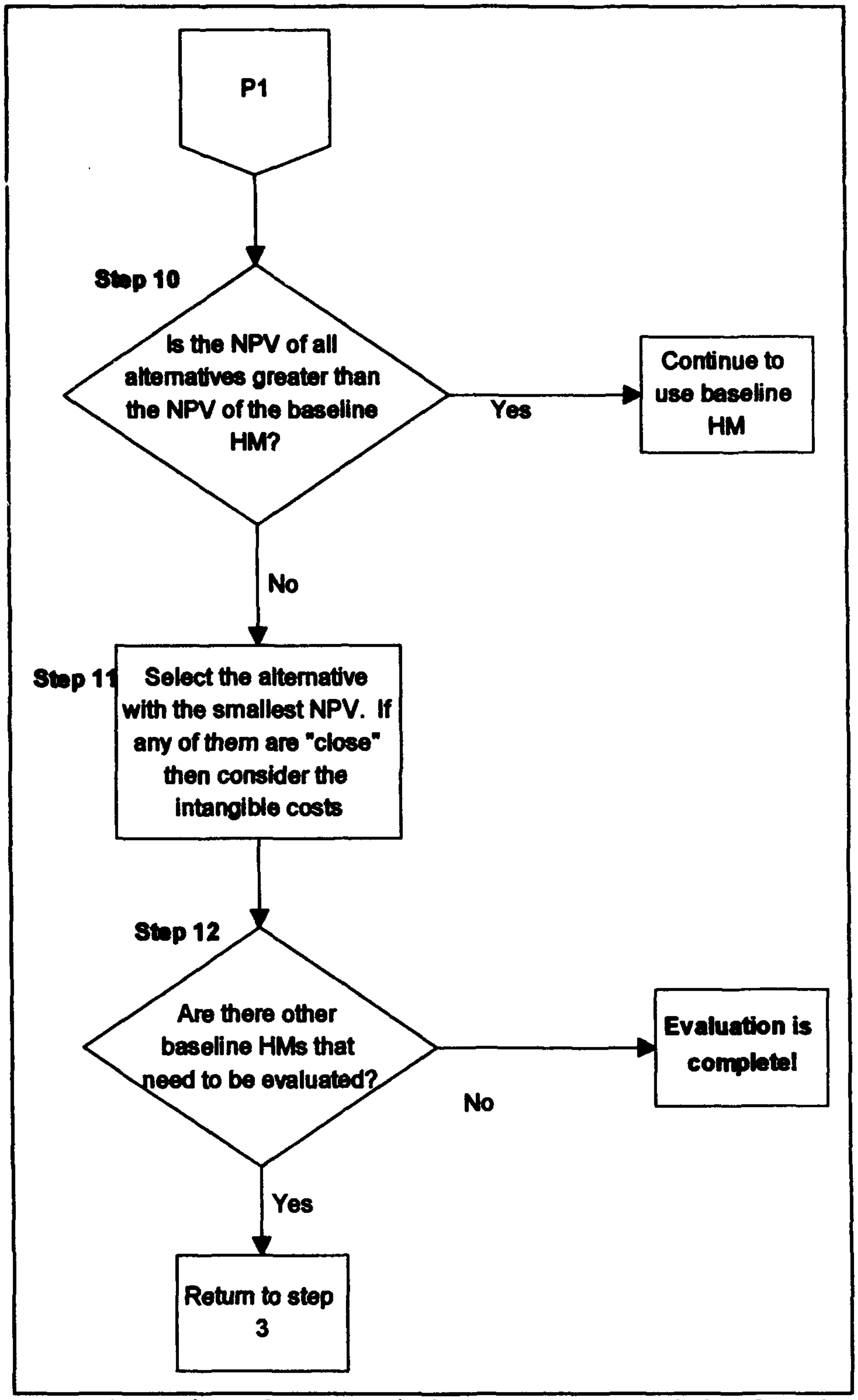

Figure 1 (continued). Decision Support Model Flowchart

Life Cycle Cost Categories

The following section contains a complete discussion of each of the LCC categories which must be evaluated in determining the total LCC of a material and its alternatives. This section also contains the equations needed to calculate the annual cost for each of the LCC categories. It should be noted that these equations may need to be altered to accommodate the various types of cost data which may be available to the users of this model.

Procurement Costs. This cost category includes the cost of purchasing hazardous materials for use in Air Force operations. It also includes the cost of transporting the materials from the manufacturer to the base if these costs are not included in the purchase price. Annual procurement cost can be computed by multiplying the quantity of material used in one year times the unit cost of the material. For example, this cost category can be calculated using the following equation:

$$C_p = C_u * Q$$

where;

C_p = annual procurement cost

C_u = cost per unit of hazardous material

Q = annual quantity of hazardous material used

Supply personnel are a good source of information concerning the unit cost of hazardous materials. Process engineers can provide estimates on hazardous material usage.

Transportation Costs. Transportation cost includes all the costs required to safely transport hazardous materials (HMs) or hazardous wastes (HWs) after a hazardous material arrives on base. This includes the cost to transport:

- HMs from base supply to the using organization
- HMs from the using organization to the use point
- HWs from the generation point to the satellite accumulation point
- HWs from the satellite accumulation point to the 90-day or 180-day accumulation point
- HWs from the 90-day or 180-day accumulation point to the base treatment storage or disposal facility (TSDF).

Annual transportation cost is the sum of the annual equipment cost and the annual manpower cost as shown in the following equation:

$$C_t = \Sigma C_e + \Sigma C_m$$

where;

C_t = annual transportation cost

C_e = annual equipment cost

C_m = annual manpower cost

Annual equipment cost includes the cost of using and maintaining equipment required to transport hazardous materials or hazardous wastes. Equipment obtained prior to the evaluation are "sunk" costs and should not be included in the analysis. This will not be the case if the equipment cost changes due to the use of the new chemical. For example, if a vehicle is amortized on a per mile basis, then a reduction in use would allow the vehicle to "last" longer and, therefore, cost less per year. Three examples of transportation equipment are vehicles, dollies, and hydraulic lifts. The annual equipment cost can be calculated by multiplying the cost of equipment per trip times the number of trips per workday times the number of workdays per year. For example:

$$C_e = C_t * \text{NUMBER} * \text{WORKDAYS}$$

where;

C_e = annual equipment cost

C_t = equipment cost per trip

NUMBER = number of trips per workday

WORKDAYS = number of workdays per year

Note, if the equipment being used is not used on a daily basis, it may be easier to use the number of trips per year instead of calculating it on a daily basis.

Annual manpower cost can be computed by multiplying the average hourly wage rate of personnel transporting HM/HW times the number of man-hours required to transport HM/HW per workday times the number of workdays per year. For example:

$$C_m = RATE * HOURS * DAYS$$

where;

C_m = annual manpower cost to transport HM/HW

RATE = average hourly wage rate of personnel transporting HM/HW

HOURS = number of man-hours per workday required to transport HM/HW

DAYS = number of workdays per year

Once again, if the material does not require transportation daily, the total man-hours can be calculated by using any other collected cost data such as data collected on a weekly or monthly basis.

Facility Costs. This category includes the cost to construct, operate, and maintain facilities which are used to store or manage hazardous materials or hazardous wastes. The annual facility cost for each facility is the sum of the annual construction costs, annual operational costs, and annual maintenance costs as illustrated in the following equation:

$$C_f = \Sigma C_c + \Sigma C_o + \Sigma C_m$$

where;

C_f = annual facility cost

C_c = annual construction cost

C_o = annual operational cost

C_m = annual maintenance cost

Construction Costs. Construction costs include the costs for buildings, building modification, capital equipment, equipment installation, utility connections, and project engineering. Sunk costs from construction that has been completed prior to this evaluation should not be included within this cost analysis. Therefore:

$$C_c = \Sigma C_b + \Sigma C_{bm} + \Sigma C_{ce} + \Sigma C_{ei} + \Sigma C_{uc} + \Sigma C_{pe}$$

where;

C_c = annual construction cost

C_b = annual building cost

C_{bm} = annual building modification cost

C_{ce} = annual capital equipment cost

C_{ei} = annual cost for equipment installation

C_{uc} = annual cost for utility connections

C_{pe} = annual project engineering cost

Base Civil Engineering is an excellent source of information for obtaining estimates for these costs.

Operational Costs. Operational cost is the sum of the portions of the utility costs (e.g., water, electricity, etc.) training costs, and manpower costs required by the using organization to operate HM/HW facilities associated with the use of a specific hazardous material. For example, if a facility's operating cost is cut in half as a result of the substitution of a material, then only half of the operating costs of the facility should be allocated to the new material's use. However, if the operational cost of a facility does not change as a result of the substitution, then these costs do not need to be included in the model. The following equation can be used to calculate the annual operating costs:

$$C_o = \Sigma C_u + \Sigma C_{tr} + \Sigma C_m$$

where;

C_o = annual operational cost

C_u = annual utility cost

C_{tr} = annual training cost

C_m = annual manpower cost

Likewise, these costs can be calculated as follows:

$$C_u = COST * WORKDAYS$$

where;

C_u = annual utility cost

COST = unit cost of utilities per workday

WORKDAYS = number of workdays per year

$$C_{tr} = \Sigma C_c + \Sigma C_{ml}$$

where;

C_{tr} = annual training cost

C_c = annual cost of the class (i.e., cost of trainer or tuition)

C_{ml} = annual lost manpower cost

$$C_{ml} = RATE_1 * HOURS_1 * NUMBER$$

where;

NUMBER = the number of people requiring training yearly

$RATE_1$ = average hourly rate of personnel receiving training

$HOURS_1$ = number of man-hours per year in training

$$C_m = RATE_2 * HOURS_2 * DAYS$$

where;

C_m = annual manpower cost to operate HM/HM facility*

$RATE_2$ = average hourly wage rate of personnel operating HM/HW facility

$HOURS_2$ = number of man-hours per workday required to operate HM/HW facility

DAYS = number of workdays per year

* This does not include the manpower cost to transport HMs/HWs. These costs are included in the transportation cost category.

Training Costs. This cost category includes the costs of training the people on the base that use hazardous materials. If the training requirements do not change as a result of the substitution, then this cost category does not need to be evaluated. The different types of training that could be required are:

- Hazardous Waste Operations Emergency Response (HAZWOPPER) Training,
- Hazard Communications Training (HAZCOM),
- Spill Response,
- Superfund Amendments and Reauthorization Act (SARA) Community Planning,
- Personal protective equipment (PPE), and
- Hazardous waste management training

Examples of the types of people that require this training are:

- Civil Engineering personnel,
- Bioenvironmental personnel,
- Hazardous material users within the using organization,
- Supply personnel, and
- Satellite accumulation point managers.

These annual costs can be calculated one of two ways depending on whether the base performs its own training or whether the training is contracted out. The annual training cost can be calculated using the following equations

$$C_{tr} = \Sigma C_c + \Sigma C_m$$

or

$$C_{tr} = \Sigma C_l + \Sigma C_m + \Sigma C_e + \Sigma C_{cons}$$

where;

C_{tr} = annual training costs

C_c = annual class costs

C_m = annual manpower loss costs

C_l = annual lecturer costs

C_e = annual equipment costs

C_{cons} = annual consumables costs

Annual Class Costs. Annual class costs include the costs for all classes contracted out for both annual refresher and initial training requirements. It can be calculated by;

$C_c = \Sigma$ (cost of initial training/person) * NEW PEOPLE +

Σ (cost of refresher training/person) * TRAINED PEOPLE

where;

NEW PEOPLE = the people who have never had the training before.

TRAINED PEOPLE = the people who have had the training before.

Manpower Loss Costs. The time that workers spend in class takes them away from their normal duties. This time away from work can be designated as manpower loss. To calculate annual manpower loss costs due to training, the following equation can be used:

$$C_m = \text{RATE} * \text{HOURS} * \text{NUMBER}$$

where;

RATE = average hourly rate of personnel receiving training

HOURS = number of man-hours per year in training

NUMBER = number of people receiving training annually

Annual Lecturer Costs. Annual costs required for the lecturers to prepare and give their lectures can be calculated by:

$$C_l = \Sigma \text{ (LECTURE * WAGE * Number of lecturers)}$$

where;

LECTURE = number of hours needed to prepare and give lecture.

WAGE = average wage rate of lecturer

Equipment Costs. The annual equipment costs can be found by multiplying the cost of each piece of equipment needed to provide training times the number of pieces of each equipment type used.

$$C_e = \Sigma(\text{EQUIPMENT} * C_p)/\text{LIFE}$$

where;

EQUIPMENT = a required piece of equipment (i.e., overhead projector)

LIFE = the expected life of the equipment

C_p = purchase cost

Consumable Costs. The consumables include such things as respirators and cartridges required for fit testing and coliwasas (disposable drum samplers) and sample bottles used for demonstration purposes.

$$C_{cons} = \Sigma(\text{CONSUMABLE} * C_p * \text{NUMBER})$$

where;

CONSUMABLE = an item required for one time use

C_p = purchase price of the consumable

NUMBER = the number of consumables

Handling Costs. This cost category includes those costs that are accumulated by a using organization due to the use of hazardous materials only. Some examples of these types of costs include the purchase of special storage containers and cabinets such as explosion-proof refrigerators, fire-proof cabinets, and acid-proof cabinets. This category also includes the lost time that the organization accumulates by making special trips to storage areas and the extra time it takes to handle the chemicals safely when transporting them or transferring them from one container to another. These costs can be calculated by using the following equation:

$$C_h = (\Sigma C_e + \Sigma C_i) / LIFE + \Sigma C_m$$

where;

C_h = total annual handling costs

C_e = cost of new equipment required

C_i = installation cost of the equipment

LIFE = expected life of the equipment in years

C_m = annual manpower cost

Manpower Costs. The manpower cost can be estimated by interviewing the workers and the supervisors within a work area and having them estimate the difference in time when performing a similar operation with and without hazardous materials. These manpower costs can then be calculated by:

$$C_m = RATE * HOURS$$

where;

RATE = average hourly rate of personnel using HM

HOURS = number of annual man-hours longer it takes when using a hazardous material

Personal Protection Costs. Many personnel on base require personal protective equipment (PPE) to perform their jobs. The organizations most likely to require this specialized equipment are:

- Supply
- The Spill team
- The using organization
- The BEE shop
- Environmental Management Office

The calculation of this cost category is actually quite easy. The BEE shop has a requirement to survey each of these areas every year and specify, among other things, the required PPE for the workers within that area. The casefiles for each work area can be reviewed, and the required PPE identified. If the items have already been purchased, then historical records can be reviewed to determine a unit cost of each item. If the items have never been purchased before, the BEE shop usually keeps a supply of these catalogs which identify the cost of PPE. The total PPE cost can, therefore, be calculated from the following equation:

$$C_{PPE} = \Sigma\ [NUMBER * C_{item} * PERIOD]$$

where;

C_{PPE} = annual personal protective equipment cost summed for each PPE item required

NUMBER = the number of people requiring that PPE item

C_{item} = cost of a specific PPE item for one person

PERIOD = the number of replacement periods per year for the PPE item

<u>Monitoring Costs</u>. Monitoring costs are divided into three major areas: waste disposal and spill residue sampling, monitoring of workplace health effects, and compliance with environmental permits. These three broad areas, when combined, give the total annual monitoring costs for a base. The equation to use to determine these costs is as follows:

$$C_{monitor} = \Sigma C_{spill/waste} + \Sigma C_{health} + \Sigma C_{permits}$$

where;

$C_{monitor}$ = annual monitoring costs

$\Sigma C_{spill/waste}$ = sum of all the costs for monitoring waste for disposal and spill residues.

ΣC_{health} = sum of all of the costs of sampling to determine health effects in the workplace due to a particular chemical

$\Sigma C_{permits}$ = sum of all of the monitoring cost required to comply with state and federal permits

There are two distinct monitoring costs associated with waste and spills--known costs and probable costs. The known costs are from the analysis of the waste that is created on a regular basis. The probable costs are those costs associated with spills involving hazardous materials. To determine how many spills will occur in any given year or how much monitoring any single spill will take requires expected value analysis through the use of historical data. The sum of the spill and waste monitoring costs ($C_{spill/waste}$) can, therefore, be calculated using the following equation:

$$C_{spill/waste} = C_{mw} + C_{ms}$$

where;

$$C_{mw} = \Sigma C_{known}$$

$$C_{ms} = \Sigma C_{probable} = \Sigma(E_{sp} * E_{sa} * C_{sa})$$

where;

$C_{spill/waste}$ = annual cost for monitoring waste and spills

C_{mw} = annual cost for monitoring waste only

C_{ms} = annual cost for monitoring spills only

C_{known} = the known costs from regular waste monitoring

E_{sp} = expected number of spills annually

E_{sa} = expected number of samples taken per spill

C_{sa} = cost per sample (i.e., analysis + supplies)

The known costs include the manpower cost required to collect, analyze, ship, and transport a sample. They also include the cost of consumables such as samplers, sample bottles, paper forms, and absorbent materials. In order to find the known cost, the following equation can be used:

$$C_{known} = (WAGES * HOURS * NUMBER) + (SAMPLES * C_{unit})$$

where;

WAGES = The average hourly wage rate of people who are collecting and processing the samples

HOURS = The total number of hours annually used in collecting waste samples for the waste being analyzed

NUMBER = The number of people required on average to collect a waste sample

SAMPLES = The number of samples required to regularly identify and process the waste stream

C_{unit} = the sampling cost per sample

The calculation of probable costs associated with accidental spills is not a trivial undertaking. The calculation relies on the calculation of an expected value. See Appendix C for an example of expected value calculations. It is also important to note that when calculating the cost of monitoring a spill, the man-hours used should be applied to emergency response and the personal protective equipment (PPE) used should be accounted for under the PPE category.

Another type of monitoring cost is the cost of monitoring that is performed during shop surveys. All of these costs are known costs and can be computed by determining the number of personal samples and area samples required for the particular chemical in a work area per year. This number is then multiplied with the same C_{unit} of sampling for that particular chemical. Added to this cost is the manpower costs used annually. To determine the number of samples required each year, BEE should be consulted. These costs of health monitoring can be calculated using the following equation:

$$C_{health} = \Sigma[(PERSONAL + AREA) * C_{unit}] + WAGES * HOURS * NUMBER$$

where;

C_{health} = sum of all of the costs of sampling to determine health effects in the workplace due to a particular chemical

C_{unit} = the sampling cost per sample (i.e., (supplies + analysis)

PERSONAL = number of personal samples required per year for that chemical

AREA = number of area samples required per year for that chemical

WAGES = The average hourly wage rate of people who are collecting and processing the samples

HOURS = The total number of hours annually used in collecting samples for the people being monitored

NUMBER = The number of people required on average to collect a personal or area monitoring sample

<u>Permit Monitoring Costs</u>. The last type of monitoring costs includes the monitoring required by permits. Permits are required for the National Pollution Discharge and Elimination System (NPDES), the Clean Air Act, and the new Clean Water Act in terms of stormwater discharge. If any of these permits require sampling for the particular chemical that is being evaluated by the model,

then the costs associated with that sampling should be included in the total life cycle costs. To calculate these costs, the number of samples required per year must be multiplied times the C_{unit} of sampling for the particular chemical. The unit cost of sampling may be obtained from the BEE or the analysis lab. The number of samples required yearly can be determined by examining the permit. It should be noted that the manpower hours used to monitor permits is included under the liability cost category. The following equation can be used to calculate the annual monitoring costs for all permits:

$$\Sigma C_{permits} = \Sigma\left[(\text{samples/year}) * C_{unit}\right]$$

where;

$\Sigma C_{permits}$ = sum of all of the monitoring costs required to comply with permit requirements

sample/year = the number of samples required for a specific chemical for a specific permit per year

C_{unit} = the sampling cost per sample

<u>Medical Costs</u>. There are many medical costs associated with the use of hazardous materials. These costs fall into the following cost sub-categories:

- physical exams
- administrative
- surveillance
- BEE shop surveys
- lost time due to physicals

Each of these sub-categories will be addressed separately. The entire cost of a medical exam or the administrative support required for the medical exam can not be placed on a single chemical unless that chemical is the only one in use that is driving the requirement for the exam. If multiple chemicals are driving the medical requirements, then some of the costs can be attributed to that chemical. For instance, if a medical test is being done on the blood looking for the effects from two different hazardous chemicals, then half of the cost of the test can be applied to each chemical. On the other hand, if a patient requires a physical due to occupational exposure to multiple chemicals, and one chemical is removed from the work area, then none of the costs of the physical exam should be attributed to the chemical in question. This is because the exam is not performed differently when only one of many chemicals is removed from a workplace.

Physical Exam Costs. The cost of performing a physical exam can best be calculated through interviews with the medical staff. The medical staff determines who requires regular exams, the frequency of exams, and what chemicals drive the requirement. The medical staff will also be able to determine how much time a physical takes their personnel, including records' reviews and follow-up paperwork. Finally, the medical personnel will be able to identify which exams are performed using only a doctor or nurse and which require multiple medical staff members. To calculate the cost of a physical exam, the following equation should be used:

$$C_{pe} = (EXAMS_d * DOCWAGES * TIME_{appt}) + (EXAMS_n * NURSEWAGES * TIME_{appt}) + (EXAMS_m * SUMWAGES * TIME_{appt})$$

where;

C_{pe} = cost for all physical exams

$EXAMS_d$ = The total number of exams per year by the doctor required for all people on the base due to the sole use of the chemical in question

$EXAMS_n$ = The total number of exams per year by the nurse required for all people on the base due to the sole use of the chemical in question

$EXAMS_m$ = The total number of exams per year by multiple medical staff members required for all people on the base due to the sole use of the chemical in question

DOCWAGES = the average pay per hour for a physical exams' doctor

NURSEWAGES = the average pay per hour of an occupation medicine nurse or equivalent

$TIME_{appt}$ = the number of hours that an average appointment takes

SUMWAGES = the sum of the average pay per hour of the multiple staff members required for multiple staff members

Administrative Costs. The administrative costs within a clinic are incurred each time a patient goes to the hospital. These costs include the manpower required to schedule the appointment, obtain the medical records, and perform the initial screening of the patient and the medical record. The specific amount of time spent on these functions will vary from clinic to clinic. The best source of information for these costs are the clinic or hospital administrator and his staff. The equation used to determine the annual costs of these administrative services is the calculation of manpower hours used as follows:

$$C_{admin} = HOURS * APPT * WAGES$$

where,

C_{admin} = the total annual administrative costs

HOURS = the total manpower hours used per appointment in administrative functions such as medical records, appointments scheduling, and records screening.

APPT = the total number of medical appointments required annually from the use of the chemical being analyzed.

WAGES = the average wages of the personnel performing administrative work for medical appointments

<u>Surveillance Costs</u>. The surveillance costs are those costs incurred from follow-up exams and tests that are ordered by the physical exams physician. Some of the other medical areas that a patient can be referred to are:

- Military Public Health
- Laboratory
- Radiology
- Bioenvironmental Engineering
- Opthamology

- other specialists such as neurologists, dermatologists, audiologists, etc.

Each of these sections incurs different types of costs. The main costs are either from manpower hours required to evaluate the patient and/or run a required test and the actual costs of tests themselves. An important aspect to realize about these costs is that they are not fully known costs. Each doctor can request a different test battery. Additionally, a doctor will only request follow-up care when he or she feels it is necessary and, therefore, does not always request additional tests. The best way to obtain data on how many referrals to another clinic or lab are made by the doctors for a specific chemical is to look at the historical records. Once this is done and it is known how many tests were requested in the past, it is important to interview the doctors to see if they expect that number to go up or down in the coming year. For each referral clinic or lab, the expected manpower costs as well as the expected cost of performing tests can be calculated and summed up to obtain the total surveillance costs. The following equation summed over each lab or clinic can be used as a guideline for this analysis:

$$C_{surv} = \Sigma(C_{man} + C_{test})$$

where;

C_{surv} = the total cost of surveillance due to exposure to a chemical for all referral clinics and labs

C_{man} = the manpower costs for each clinic or lab to evaluate patient referrals and to perform tests

C_{test} = the cost of the requested tests themselves

The manpower costs for each lab or clinic in this equation can be calculated using the following equation:

$$C_{man} = E_{referrals} * WAGES * HOURS$$

where;

$E_{referrals}$ = the expected number of referrals to this clinic (assessed from historical records and doctors' interviews)

WAGES = the average wage rate of the laboratory or clinic performing the referral services

HOURS = the average number of hours a referral takes

The cost of the requested tests themselves can be calculated similarly with the expected number of tests performed by each lab multiplied by the cost of a single test.

$$C_{test} = E_{referrals} * E_{tests} * C_{test}$$

where;

$E_{referrals}$ = same as above

E_{test} = the expected number of tests performed because of the specific chemical per referral

C_{test} = the average cost per test that is performed

<u>BEE Shop Survey Costs</u>. Most of the costs associated with a chemical in a BEE shop survey have been included above under monitoring costs and in surveillance costs' categories. The primary costs left are those man-

hours that are reduced due to the use of the new chemical or the elimination of the old. Some examples of these man-hour savings are as follows: less research being required to determine a chemicals hazards, the removal of tracking required by the Issue Exception Code Listing, the elimination of the work area as a shop, or the reduction of ventilation surveys from quarterly to annually. The equation that can be used for these costs is:

$$C_{BEE} = \sum (\text{WAGES} * \text{HOURS})$$

where;

WAGES = the wage rate of the BEE personnel performing the survey

HOURS = the number of hours a survey takes

The summation in the above equation covers each person that is working on a particular survey. For example, the report may be written by a junior enlisted member; but it may be reviewed and corrected by a senior enlisted member.

<u>Lost Time Due to Physicals Costs</u>. Each person that receives a physical due to the use of a hazardous material must leave their work area and spend time getting their physical. This time away from work represents a loss to the organization because these people are not performing the work that they have been hired to accomplish. The time away from work includes time for travel, in waiting rooms, for examinations, and for appointments at referral clinics. These costs can only be associated with the change in a usage of a hazardous material. For example, if through the

replacement of that material, the physical process takes a different amount of time. The following equation can be used to calculate the annual costs of lost time due to physicals:

$$C_{LT} = WAGES * (APPT + OTHER) * NUMBER$$

where;

C_{LT} = the total cost of lost time due to physical exams

WAGES = the average wages per hour of all people receiving medical exams due to the use of the material being investigated

APPT = the time that the actual appointment takes to perform the physical exam

OTHER = the additional time that other aspects of a physical takes (i.e., travel time, waiting time, time at other clinics)

NUMBER = the number of individuals that are receiving a physical exam due to the use of the hazardous chemicals that is being investigated.

<u>Emergency Response Costs</u>. This cost category consists of the cost of emergency response equipment and the manpower costs required to perform emergency response activities including exercises. This does not include the costs associated with training, monitoring, and transportation of waste which are included in their respective categories. Emergency response equipment cost includes the cost of items such as booms, spill kits, absorbent material, shovels, and the cost of using cleanup equipment such as dump trucks and excavators. Manpower costs must be calculated for all spill

response team members. The annual emergency response cost can be calculated using the following equation:

$$C_{er} = (\Sigma C_e + \Sigma C_m) * E_{er}$$

where;

C_{er} = annual emergency response cost

C_e = emergency response equipment cost per response

C_m = emergency response manpower cost per response

E_{er} = expected number of emergency responses per year

$$C_m = RATE * HOURS_1 * NUMBER_1 + ORGRATE * HOURS_2 * NUMBER_2$$

where;

RATE = average hourly wage rate of personnel performing emergency response activities

$HOURS_1$ = estimated man-hours required to perform emergency response activities per year

$NUMBER_1$ = number of personnel used in response

ORGRATE = weighted average hourly wage rate of personnel performing emergency response activities

$HOURS_2$ = estimated man-hours required to perform emergency response activities per year

$NUMBER_2$ = Number of personnel displaced from work areas due to the response

Disposal Costs. Disposal cost includes those costs required to dispose of hazardous wastes which are generated on base as a result of using hazardous materials in Air Force operations. This includes manpower costs, equipment costs and treatment/disposal costs. Therefore,

$$C_d = \Sigma C_m + \Sigma C_s + \Sigma C_{td}$$

where;

C_d = annual disposal cost

C_m = annual manpower cost required to dispose of HW

C_s = annual supply cost required to dispose of HW

C_{td} = annual cost for treatment/disposal of HW

<u>Manpower Costs</u>. The management of hazardous wastes involves a number of base organizations including the Environmental Management Office, the Bioenvironmental Engineering Management Office, Base Supply, and the using organization. Manpower cost includes the cost required to manifest, manage, inspect, and track hazardous waste. It also includes the manpower costs required for reporting hazardous waste activities and obtaining necessary permits. This does not include the manpower cost required by the using organization to manage hazardous waste while the hazardous waste is located at the using organization's facility. These costs are included in the facility cost category. The total annual manpower cost is the sum of the manpower cost for each organization involved in the hazardous waste disposal process and can be computed using the following equation:

$$C_m = \Sigma(\text{RATE} * \text{MAN-HOURS})$$

where;

C_m = annual manpower cost required to dispose of HWs

RATE = average hourly wage rate of personnel disposing of HWs

MAN-HOURS = number of man-hours per year required to dispose of HWs

Supply Costs. Annual supply costs include the cost of consumable items required to properly manage hazardous wastes. Such costs will include items such as HW labels, drums, containers, funnels, spill containment material, eyewashes, emergency showers, etc. Therefore,

$$C_s = \Sigma(\text{annual supply costs})$$

Treatment/Disposal Costs. Most hazardous wastes generated during Air Force operations are treated or disposed of off-site by local contract. Therefore, annual disposal costs can be computed by multiplying the cost per unit to dispose of hazardous wastes times the number of units of hazardous waste disposed of each year.

$$C_{td} = C_u * \text{UNITS}$$

where;

C_{td} = annual treatment/disposal cost

C_u = the cost per unit of hazardous waste disposal

UNITS = the number of units disposed of per year

Some hazardous wastes may be treated on base by an industrial wastewater treatment plant (IWTP). If this is the case, annual disposal cost can be calculated by multiplying the unit cost of IWTP disposal times the number of units of hazardous waste treated by the IWTP. The Base Environmental Management Office will be able to provide the unit cost of disposal for each hazardous waste generated on base and the annual quantity generated.

Liability Costs. Liability costs are particularly important cost considerations due to the potential magnitude of these costs. For the purposes of this model, liability costs have been identified as the costs associated with toxic torts, real property damage, natural resource damage, regulatory fines/penalties, permitting fees, regulatory correspondence, and long-term liability cost due to landfilling hazardous waste. Therefore, the total annual liability cost is the sum of all of these cost elements as illustrated in the following equation:

$$C_L = C_{tt} + C_{rpd} + C_{nrd} + C_{fp} + C_{pf} + C_{rc} + C_{lhw}$$

where;

C_L = annual liability cost

C_{tt} = annual cost due to toxic torts

C_{rpd} = annual cost due to real property damage

C_{nrd} = annual cost due to natural resource damage

C_{fp} = annual cost due to regulatory fines/penalties

C_{pf} = annual cost due to permitting fees

C_{rc} = annual cost due to regulatory correspondence

C_{lhw} = annual cost due to liability for landfilling hazardous waste

Toxic Tort Costs. Toxic tort costs include the cost of settling toxic tort claims as a result of exposure to hazardous materials or hazardous wastes (3:4-54). This will consist of claims due to wrongful death, pain and suffering, lost time due to disability and associated medical costs. In developing the HMLCCE, the Air Force determined that the average claim for toxic torts per person injured was approximately $56,000 (3:4-54). In determining the number of people injured as a result of using hazardous materials and hazardous waste, the EPA suggests a default value (best case) of 10 injured persons per year for an average firm (19:C-4). Based on this value, the Air Force determined that 10 injuries per 500,000 lbs of waste disposed off-site as a good approximation for estimating toxic tort cost (3:4-54). Using these values, the annual cost for toxic torts can be calculated using the following formula:

$$C_{tt} = 1.12 * Q$$

where;

C_{tt} = annual cost for toxic torts

1.12 = 2×10^{-5} (10 injuries/500,000 lbs of HW) times $56,000 (avg. cost per injury)*

Q = annual quantity in pounds of hazardous waste disposed of off-site

* Note - The user of this model may wish to use an alternate value for 1.12 if local historical data indicates that another value may be more appropriate.

<u>Real Property Damage Costs</u>. The cost of real property damage occurs whenever real property is damaged as

a result of contamination due to hazardous materials and hazardous waste. In most cases, the real property is devalued and the owners seek restitution for any damages caused by the contamination. In approximating the cost of real property damage, the Air Force in developing the HMLCCE determined that 1.6 acres are contaminated per 100,000 lbs of waste disposed off-site (3:4-59). The EPA has also determined that the percentage of devaluation of contaminated real property is approximately 30 percent (3:4-59).

Using this information, the annual cost of real property damage can be approximated using the following equation:

$$C_{rpd} = 4.8 \times 10^{-6} * Q * \text{VALUE}$$

where;

C_{rpd} = annual cost of real property damage

48×10^{-6} = 1.6×10^{-5} (1.6 acres/100,000 lbs of HW) times 0.3 (30% devaluation)*

Q = annual quantity in pounds of hazardous waste disposed of off-site

VALUE = the value of real property per acre prior to the contamination

* Note - The user of this model may wish to use an alternate value for 4.8×10^{-6} if local historical data indicates that another value may be more appropriate.

Natural Resource Damage Costs. Natural resource damage or destruction usually results from hazardous material/waste spills or contamination due to leaking landfills or underground storage tanks. Natural resource damage costs are all the costs required to restore natural resources (i.e., fish, wildlife, wetlands, forest, etc.) to their original condition. The EPA estimates that it costs approximately $804,651 (FY91$) per acre to restore natural resources to their original condition (3:4-163). According to the methodology outlined in the Air Force's HMLCCE, the affected area for natural resource damage/destruction is approximately three acres per 500,000 lbs of hazardous waste disposed of off-site (3:4-163). Using these figures, the annual cost due to natural resource damage can be computed as follows:

$$C_{nrd} = 4.83 * Q$$

where;

C_{nrd} = annual cost due to natural resource damage

4.83 = 6×10^{-6} (3 acres/500,000 lbs of HW) times $804,651 (cost to restore one acre of natural resources)*

Q = annual quantity in pounds of hazardous waste disposed of off-site

* Note - The user of this model may wish to use an alternate value for 4.83 if local historical data indicates that another value may be more appropriate.

Regulatory Fines/Penalties Costs. The evaluation of the costs for regulatory fines/penalties involves probability analysis. Computation of the expected cost for all possible regulatory fines/penalties which may occur over the life cycle of the hazardous material is the accumulated product of the probability of receiving a fine or penalty and the average cost of each fine or penalty. For example, the annual cost due to regulatory fines/penalties can be computed using the following equation:

$$C_{fp} = \Sigma(P_{fp} * COST)$$

where;

C_{fp} = annual cost due to regulatory fines/penalties

P_{fp} = probability of receiving a fine/penalty

COST = the average cost of fine/penalty

Permitting Fee Costs. Permitting fees may be required for a variety of different sources including hazardous waste permits, national pollutant discharge elimination system (NPDES) permits, and 1990 Clean Air Act permits. These fees may vary greatly depending on the type of operation and the location of the operation. The two main types of permitting cost include constant annual cost and unit-based cost. Constant costs include items such as set fees, while unit-based costs include fees charged per unit of waste. Therefore, the annual cost due to permitting fees is the summation of the accumulated constant cost and the accumulated unit-based cost. For example, the following equation illustrates this cost calculation.

$$C_{pf} = \Sigma C_c + \Sigma C_{ub}$$

where;

C_{pf} = annual cost for permitting fees

C_c = annual constant cost

C_{ub} = annual unit-based cost

$$C_{ub} = C_u * UNITS$$

where;

C_{ub} = annual unit-based cost

C_u = permit cost per unit released into the environment

UNITS = number of units released each year

<u>Regulatory Correspondence Costs</u>. This cost category includes all the cost incurred by the Air Force legal personnel in meeting regulatory requirements (e.g., resolving Notices of Violation (NOVs), settling legal issues with regulatory agencies, etc.). The annual cost for regulatory correspondence as illustrated in the following equation is the accumulated product of the number of man-hours required per year and the average hourly wage rate of the legal personnel performing correspondence activities.

$$C_{rc} = \Sigma(\text{MAN-HOURS} * \text{RATE})$$

where;

C_{rc} = annual cost for regulatory correspondence

MAN-HOURS = number of man-hours per year required to perform correspondence activities for the material being evaluated.

RATE = average hourly wage rate of legal personnel performing correspondence activities

<u>Liability Costs for Landfilling Hazardous Wastes</u>. The liability cost associated with landfilling hazardous

waste is a very important cost consideration which must be evaluated to determine the true LCC of using hazardous materials. This cost consideration was the focus of a doctoral dissertation by Captain James Aldrich, AFIT PhD Student at the University of Cincinnati (1). Captain Aldrich developed a methodology using expected value analysis to predict the long term liability cost of landfilling hazardous waste. According to his methodology, the liability cost of landfilling hazardous waste is the product of the probability of landfill failure and the cost of hazardous waste destruction as a result of landfill failure (2:270). Using this methodology, the annual liability costs of landfilling hazardous wastes can be calculated using the following equation:

$$C_{lhw} = f_l * C_d * \text{QUANTITY}$$

where;

C_{lhw} = annual liability cost for landfilling hazardous waste

f_l = liability factor (See Appendix D for sample calculations)

C_d = hazardous waste destruction cost (\$/pound)

QUANTITY = annual quantity in pounds of hazardous waste disposed of in a landfill

Intangibles. Intangible costs are typically difficult to quantify or assign an accurate monetary value. Some of the intangible costs of using hazardous materials may include (32:4-9):

- poor public image
- bad press
- poor Air Force/regulator relations
- increased health maintenance costs
- poor employee attitudes

Although these costs are often difficult to quantify, they should be incorporated in the decision-making process (2:182). At the very least, decision-makers should qualitatively evaluate intangible costs whenever the economic analysis of the tangible costs (e.g., other cost categories) does not result in a clear "winner" (i.e., if any of the alternatives are "close" in terms of their Net Present Value).

Depending on the political climate and the organization's objectives, the value of these costs may vary significantly. In some cases, these costs can be significant enough to completely override the economic analysis of the tangible costs. In any case, these intangible costs should be given appropriate considerations in determining the feasibility of using alternative hazardous materials.

Additional Costs Considerations

In developing this model, every attempt was made to determine the total LCC associated with a baseline hazardous material and its alternatives. If there are additional costs which are specific to an operation and are not included in this model, then cost equations should be developed to include these costs in the analysis. Also, data may be collected that does not "fit" into the equations in their current forms. Therefore, the equations or the cost data units should be altered accordingly.

V. Case Study

Introduction

This case study illustrates the use of the decision support model using the Tissue Processing operation located at Brooks AFB, Texas. The primary reason for selecting this type of operation was that it currently generates over 50% of the total hazardous waste on Brooks AFB. Another reason for selecting this operation was that viable alternatives were identified for several of the baseline hazardous materials (HMs) which are currently being used. In addition, the organization had the authority to make the substitution by not being required to use specific materials according to a Technical Order (TO).

Process Description

The tissue processing operation located in Bldg. 125 (Rms. 355 and 392) is part of the Anatomic Pathology Laboratory. This operation consists of trimming (grossing) tissues to appropriate sizes and placing these sample tissues into cassettes for further processing. These tissue cassettes are then sent to the LX-300 Tissue Processor. Once the cassettes are inside the processor, they are bathed in a series of formaldehyde solutions (10% formalin) and a series of ethyl alcohol solutions. These chemicals "fix," dehydrate, and prepare the samples to allow them to be infused with paraffin which is automatically added by the processor. Each of the bathing steps results in a waste stream consisting mainly of spent 10% formalin and ethyl alcohol which is collected in waste bottles. Finally, xylene and absolute ethyl alcohol are added as clearing agents to remove the paraffin from the lines and thus prepare the machine for the next sample. The samples, which are now infused and attached to a cassette with paraffin, are sliced using a micro-slicer and placed on a slide. The slide is then stained using solutions of Histoclear®, ethyl alcohol, stain, and acid alcohol. These baths are used repeatedly using multiple racks of slides. The baths are emptied and refilled on an as-needed basis to ensure that quality slides are produced. The Histoclear®, ethyl alcohol, 10% formalin, and xylene are all collected at a satellite accumulation point and are disposed of as hazardous waste. This operation currently accounts for over 50% of the total hazardous waste generated on Brooks AFB. The percentage of each spent material to the entire waste generated on Brooks AFB is shown in Table 3 (6: Appendix B)

Table 3

Waste Percentages on Brooks AFB

Spent 10% Formalin	35.75%
Spent Clearing Agents (xylene and Histoclear®)	7.35%
Spent Alcohol Solutions	8.02%
Percentage of Total Waste on Brooks AFB	51.12%

Example Application of the Decision Support Model

The following section illustrates how the decision support model was used in conducting the case study.

Step 1. ***For the chosen operation, determine the baseline (i.e., current) hazardous materials being used. The Bioenvironmental Engineering Office (BEE) can assist in determining which operations use hazardous materials and which materials within those operations are considered hazardous.***

This step was completed by reviewing the information contained in the Brooks AFB Waste Stream Analysis Study (6). The Tissue Processing operation was identified as an appropriate operation for evaluation due to the amount of hazardous materials used in the operation. The information set forth in the waste stream analysis study proved to be very helpful in determining which base operations used hazardous materials and the quantities of hazardous waste generated from the use of the materials. The following baseline hazardous materials were identified: 10% formalin, ethyl alcohol, xylene, and Histoclear®.

Step 2. ***Determine if any alternative materials are available as substitutes for the hazardous materials currently being used in the operation. These alternative materials can be identified through a review of the Technical Orders, during Pollution Prevention Audits, from the BEE Office, from inquiries to other bases performing***

similar operations, and from technical journals and other publications.

Possible alternatives for all of the baseline hazardous materials (HMs) except ethyl alcohol were identified by contacting other laboratories which are currently performing similar tissue processing operations. These laboratories included: Emory Medical Center (Pathology Laboratory) in Atlanta, Georgia, and HCA Palmyra Medical Center (Histology Laboratory) in Albany, Georgia. After identifying possible alternatives, a chemical supply company (S & S Chemical Company of Georgia, Inc.) was contacted to determine the feasibility of using these alternatives in the Tissue Processing operation at Brooks AFB (46). As a result, several non-hazardous alternatives were identified as possible substitutes. These alternatives are listed in Table 4 and are described following the case study calculations in Appendix E.

Table 4
Alternatives for Baseline Hazardous Materials

Baseline HM	Alternative
10% formalin	Normalin®
Clearing Agents (xylene and Histoclear®)	Slide-Brite®

This step determined that there were no viable alternatives for the ethyl alcohol solutions currently being used in this operation.

Step 3. ***Select one of the baseline hazardous materials identified in step 1 and one of the alternatives identified in step 2. The later selection can be any of the possible alternatives identified in the previous step.***

The first baseline hazardous material selected for evaluation was the 10% formalin solution. Since there was only one viable alternative, Normalin®, identified in step 2 as a possible substitute, Normalin® was the only alternative evaluated.

Step 4. ***Estimate an appropriate life cycle (number of years) to be evaluated. The selected life cycle for evaluation should be the same for both the baseline hazardous material and the selected alternative. The appropriate life cycle should extend into the future a sufficient length of time to account for all of the costs that will occur due to the use of the materials. However, it should be noted that increasing the life cycle increases the uncertainty of the cost factors involved. To minimize these uncertainties, the life cycle should be selected with care.***

In terms of this evaluation, all of the costs were evaluated as annual reoccurring costs beginning in year one. Therefore, the annual costs would not differ in later years except for the extra cost due to inflation and/or real price increases. Since no additional costs were required in later years, a life cycle of one year could be used for this evaluation. However, for purposes of demonstrating the use of the present value analysis, this evaluation used a life cycle of five years.

Step 5. ***Evaluate each of the LCC categories listed in Table 2 and discussed later in this chapter to determine***

which cost categories will have a monetary change as a result of the substitution of the selected alternate material. Changes may occur in a cost category due to actual monetary differences (e.g., differences in the cost of a particular cost category) or from differences in the time frame that the costs are incurred (e.g., costs incurred at different times). Many of the cost categories will not change as a result of the substitution. These categories do not need to be calculated to determine the economic feasibility of the substitute.

During the discussions with the personnel at Brooks AFB, it was determined that nine of the cost categories would have a change as a result of the substitution of Normalin® for the 10% formalin. These cost categories included:

- Procurement
- Transportation
- Personal Protection
- Monitoring
- Medical
- Emergency Response
- Disposal
- Liability

The remaining cost categories (Training, Facility, and Handling) would not change as a result of the substitution. For example, the training performed by the base and the using organization would not change because the using organization would still be using hazardous materials. Since there would be no new requirements for facilities, there would be no additional facility cost. The using organization would not change any of its operating procedures; therefore, handling costs would not change.

Step 6. ***For each cost category, except intangible costs, identified as being different in either of the two ways described in step 5, calculate the annual cost using the equations outlined in chapter IV for the baseline material and the substitute material over their entire life cycles.***

A detailed analysis of Brooks AFB's operations through site visits, historical record searches, and personal interviews was accomplished from 11-17 July 1993. During this time, cost data was collected to determine the annual costs of using 10% formalin and the substitute (Normalin®). The calculations for each of the cost categories are included in Appendix E. Summaries of these life cycle costs are provided in Table 5.

Step 7. ***Calculate the total annual cost (i.e., sum of the individual cost categories) for the baseline material and the substitute material over their entire life cycles.***

Refer to Table 5 for the total annual cost of 10% formalin and Normalin®.

Table 5

Annual Costs

LCC Category	Baseline HM (10% Formalin)	Alternative (Normalin®)
Procurement	$1404.00	$291.69
Transportation	$1107.01	$0.00
Facility	No Change	No Change
Training	No Change	No Change
Handling	No Change	No Change
Personal Protection	$17.28	$0.00
Monitoring	$2257.72	$0.00
Medical	$678.26	$0.00
Emergency Response	$173.44	$0.00
Disposal	$21,672.21	$0.00
Liability	$50,898.89	$0.00
Total Annual Costs	**$78,208.81**	**$291.69**

Step 8. ***Inflate each of the total annual costs calculated in step 7 using the inflation tables, provided in Appendix A, over the selected life cycle. Next, calculate the Net Present Value of the baseline hazardous material and the substitute material using present value analysis. See Appendix B for a discussion of Present Value Analysis.***

Since the total annual costs will remain the same except for the effects of inflation and/or real price increases, inflated costs were used to determine the total annual cost in later years. The inflated costs which are provided in Table 6 can then be brought back to the current year (FY92) to obtain a total Net Present Value for the 10% formalin and its alternative (Normalin®). These calculated results are also provided. The inflation factors in Appendix A for O&M-type funds of FY92 were used to determine the total inflated annual cost over the selected life cycle of five years. The inflated total annual costs were thus determined by multiplying the inflation factors associated with the later year times the current (FY92) total annual cost.

Table 6

Inflated Total Annual Costs

Material	1992 Year 1 ($)	1993 Year 2 ($)	1994 Year 3 ($)	1995 Year 4 ($)	1996 Year 5 ($)
10% Formalin	78,208.81	80,085.82	82,041.04	83,918.05	85,795.06
Normalin®	291.69	298.69	305.98	312.98	319.98

The net present value of these totals using the standard government discount rate of 10% is as follows:

Net Present Value of 10% Formalin:

$$NPV_{1992-1996} = PV_{1992} + \frac{FV_{1993}}{(1+r)^n} + \frac{FV_{1994}}{(1+r)^n} + \frac{FV_{1995}}{(1+r)^n} + \frac{FV_{1996}}{(1+r)^n}$$

$$NPV_{1992-1996} = \$78,208.81 + \frac{\$80,085.82}{(1+.10)^1} + \frac{\$82,041.04}{(1+.10)^2} + \frac{\$83,918.05}{(1+.10)^3} + \frac{\$85,795.06}{(1+.10)^4}$$

$$= \mathbf{\$340,464.66}$$

Net Present Value of Normalin®:

$$NPV_{1992-1996} = PV_{1992} + \frac{FV_{1993}}{(1+r)^n} + \frac{FV_{1994}}{(1+r)^n} + \frac{FV_{1995}}{(1+r)^n} + \frac{FV_{1996}}{(1+r)^n}$$

$$NPV_{1992-1996} = \$291.69 + \frac{\$298.69}{(1+.10)^1} + \frac{\$305.98}{(1+.10)^2} + \frac{\$312.98}{(1+.10)^3} + \frac{\$319.98}{(1+.10)^4}$$

$$= \mathbf{\$1,269.81}$$

Step 9. ***Repeat steps 3 through 8 to evaluate the economic feasibility of other possible alternatives.***

There were no other alternatives evaluated for this case study. All other suggested alternatives were rejected by the using organization due to lack of performance in previous trials.

Step 10. ***If the Net Present Value for all of the alternatives is greater than the baseline material, then continue to use the baseline material.***

Since the Net Present Value of the baseline material is more than its alternative, this does not apply in this case.

Step 11. ***Select the alternative which results in the greatest cost savings (i.e., the smallest Net Present Value). If any of the alternatives are "close" in terms of the Net Present Value, then intangible costs of the***

alternatives should be considered in determining the best (cost-effective) alternative.

Since the Net Present Value of Normalin® is much less than the Net Present Value of 10% formalin, the baseline material should be eliminated, and the Normalin® should be used as a replacement. This is assuming that the substitute provides an acceptable level of performance.

<u>Step 12</u>. ***If the user needs to evaluate another baseline material, he or she should return to Step 3. If the user does not need to evaluate another material, the evaluation is complete.***

For this case study, xylene and Histoclear® (baseline hazardous materials) were also identified as having a possible alternative (Slide-Brite®). Therefore, this analysis will continue by returning to Step 3.

<u>Step 3</u>. ***Select one of the baseline hazardous materials identified in step 1 and one of the alternatives identified in step 2. The later selection can be any of the possible alternatives identified in the previous step.***

The last baseline hazardous materials selected for evaluation were the clearing agents, xylene and Histoclear. Since there was only one viable alternative (Slide-Brite®) identified in step 2 as a possible substitute, Slide-Brite® was the only alternative evaluated.

<u>Step 4</u>. ***Estimate an appropriate life cycle (number of years) to be evaluated. The selected life cycle for evaluation should be the same for both the baseline***

hazardous material and the selected alternative. The appropriate life cycle should extend into the future a sufficient length of time to account for all of the costs that will occur due to the use of the materials. However, it should be noted that increasing the life cycle increases the uncertainty of the cost factors involved. To minimize these uncertainties, the life cycle should be selected with care.

In terms of this evaluation, all of the costs were evaluated as annual reoccurring costs beginning in year one. This means that the annual costs would not differ in later years except for the extra cost due to inflation. This occurred because no additional costs were required in later years. Therefore, a life cycle of one year could be used for this evaluation. However, for purposes of demonstrating the use of the present value analysis, this evaluation used a life cycle of five years.

Step 5. ***Evaluate each of the LCC categories listed in Table 2 and discussed later in this chapter to determine which cost categories will have a monetary change as a result of the substitution of the selected alternate material. Changes may occur in a cost category due to actual monetary differences (e.g., differences in the cost of a particular cost category) or from differences in the time frame that the costs are incurred (e.g., costs incurred at different times). Many of the cost categories will not change as a result of the substitution. These categories do***

not need to be calculated to determine the economic feasibility of the substitute.

During the discussions with the personnel at Brooks AFB, it was determined that four of the cost categories would be changed as a result of the substitution of Slide-Brite® for the clearing agents. These cost categories included:

- Procurement
- Transportation
- Disposal
- Liability

The remaining cost categories would not change as a result of the substitution.

Step 6. ***For each cost category, except intangible costs, identified as being different in either of the two ways described in step 5, calculate the annual cost using the equations outlined in chapter IV for the baseline material and the substitute material over their entire life cycles.***

A detailed analysis of Brooks AFB's operations through site visits, historical record searches, and personal interviews was accomplished from 11-17 July 1993. During this time, cost data was collected to determine the annual costs of using the present clearing agents and the substitute (Slide-Brite®). The calculations for each of the cost categories are included in Appendix E. Summaries of these life cycle costs are provided in Table 7.

Table 7

Annual Costs

LCC Category	Baseline HM (clearing agents)	Alternative (Slide-Brite®)
Procurement	$1,416.48	$1,365.00
Transportation	$340.21	$0.00
Facility	No Change	No Change
Training	No Change	No Change
Handling	No Change	No Change
Personal Protection	No Change	No Change
Monitoring	No Change	No Change
Medical	No Change	No Change
Emergency Response	No Change	No Change
Disposal	$4,748.34	$0.00
Liability	$10,217.48	$0.00
Total Annual Costs	**$16,722.51**	**$1,365.00**

Step 7. ***Calculate the total annual cost (i.e., sum of the individual cost categories) for the baseline material and the substitute material over their entire life cycles.***

Refer to Table 7 for the total annual cost of clearing agents and Slide-Brite®.

<u>Step 8</u>. ***Inflate each of the total annual costs calculated in step 7 using the inflation tables, provided in Appendix A, over the selected life cycle. Next, calculate the Net Present Value of the baseline hazardous material and the substitute material using present value analysis. See Appendix B for a discussion of Present Value Analysis.***

Since the total annual costs will remain the same except for the effects of inflation, inflated costs were used to determine the total annual cost in later years as shown in Table 8.

Table 8

Inflated Total Annual Costs

Material	1992 Year 1 ($)	1993 Year 2 ($)	1994 Year 3 ($)	1995 Year 4 ($)	1996 Year 5 ($)
Clearing Agents	16,722.51	17,123.85	17,541.91	17,943.25	18,344.59
Slide-Brite®	1,365.00	1,397.76	1,431.89	1,464.65	1,497.41

The inflated costs which are provided above can then be brought back to the current year (FY92) to obtain a total Net Present Value for the for the clearing agents and their alternative (Slide-Brite®). These calculated results are also provided. The inflation factors for O&M-type funds of FY92 were used to determine the inflated total annual cost over the selected life cycle of five years. The inflated total annual costs were thus determined by multiplying the inflation factors associated with the later year times the current (FY92) total annual cost. The net present value of these totals using the standard government discount rate of 10% is as follows:

Net Present Value of clearing agents:

$$NPV_{1992-1996} = PV_{1992} + \frac{FV_{1993}}{(1+r)^n} + \frac{FV_{1994}}{(1+r)^n} + \frac{FV_{1995}}{(1+r)^n} + \frac{FV_{1996}}{(1+r)^n}$$

$$NPV_{1992-1996} = \$16{,}722.51 + \frac{\$17{,}123.85}{(1+.10)^1} + \frac{\$17{,}541.91}{(1+.10)^2} + \frac{\$17{,}943.25}{(1+.10)^3} + \frac{\$18{,}344.59}{(1+.10)^4}$$

$$= \mathbf{\$\ 70{,}095.48}$$

Net Present Value of Slide-Brite®:

$$NPV_{1992-1996} = PV_{1992} + \frac{FV_{1993}}{(1+r)^n} + \frac{FV_{1994}}{(1+r)^n} + \frac{FV_{1995}}{(1+r)^n} + \frac{FV_{1996}}{(1+r)^n}$$

$$NPV_{1992-1996} = \$1{,}365.00 + \frac{\$1{,}397.76}{(1+.10)^1} + \frac{\$1{,}431.89}{(1+.10)^2} + \frac{\$1{,}464.65}{(1+.10)^3} + \frac{\$1{,}497.41}{(1+.10)^4}$$

$$= \mathbf{\$\ 5{,}691.86}$$

Step 9. ***Repeat steps 3 through 8 to evaluate the economic feasibility of other possible alternatives.***

There were no other alternatives evaluated for this case study. All other suggested alternatives were rejected by the using organization due to lack of performance in previous trials.

Step 10. ***If the Net Present Value for all of the alternatives is greater than the baseline material, then continue to use the baseline material.***

Since the Net Present Value of the baseline material is more than its alternative, this does not apply in this case.

Step 11. ***Select the alternative which results in the greatest cost savings (i.e., the smallest Net Present Value). If any of the alternatives are "close" in terms of the Net Present Value, then intangible costs of the alternatives should be considered in determining the best (cost-effective) alternative.***

Since the Net Present Value of Slide-Brite® is much less than the Net Present Value of the presently used clearing agents, the baseline material should be eliminated, and Slide-Brite® should be used as a replacement. This is assuming that the substitute provides an acceptable level of performance.

Step 12. ***If the user needs to evaluate another baseline material, he or she should return to Step 3. If the user does not need to evaluate another material, the evaluation is complete.***

For this case study, all of the baseline materials identified as having a possible alternative were analyzed. Therefore, the evaluation is complete.

Conclusion

The case study demonstrates the use of the decision support model in evaluating the economic feasibility of using alternatives for hazardous materials currently being used in an Air Force operation. This model clearly illustrates how the total LCC of materials differs from one hazardous material to another hazardous material, and how these costs vary with the substitution of non-hazardous alternatives.

For example, the annual total LCC of using 10% formalin (a hazardous material) is $78,208.81 as compared to $16,722.51 for using clearing agents which are also hazardous materials. A reason for this cost difference is that 10% formalin contains formaldehyde which is a suspect human carcinogen and a known animal carcinogen. Therefore, there were additional LCCs such as personal protection, monitoring, and medical costs associated with the use of the 10% formalin. However, the largest difference is due to the difference in volume of hazardous waste generated as a result of using these hazardous materials. For example, even though the spent 10% formalin and the spent clearing agents are disposed of in the same manner, there is a noticeable difference in the disposal and liability costs associated with the use of these materials due to the difference in volume of hazardous waste generated.

In addition, there is a substantial difference in the total annual LCC associated with the substitution of a non-hazardous alternative (Normalin®) for a hazardous material (10% formalin). For instance, the total annual savings of using Normalin® instead of 10% formalin is $77,917.12 ($78,208.81 - $291.69). This information could be especially useful in justifying the purchase of a "more expensive" alternative, in terms of its procurement costs. In other words, if the procurement cost of the non-hazardous alternative, Normalin®, was 200 times more expensive than its current procurement cost (200 x $291.69 = $58,338.00), there would still be an annual cost savings of $19,870.81 ($78,208.81 - $58,338.00) to the Air Force. This clearly illustrates the potential cost saving associated with using a non-hazardous alternative such as Normalin® in place of a hazardous material.

Although this model may seem to be long and complicated, the equations provided are easy to use; and the cost data required for these equations is readily available at the base-level organizations. This allows local decision-makers the luxury of determining the cost-effectiveness of using various alternatives in place of hazardous materials currently used in their operations.

VI. Research Summary

This research examined the life cycle costs (LCCs) associated with the management of hazardous materials, particularly within the Air Force. However, the primary objective of this study was to develop a decision support model that would allow its users to evaluate the economic feasibility of material substitution for hazardous materials currently being used in Air Force operations in support of the Air Force's Pollution Prevention Program. After reviewing existing LCC models, it was determined that none of these models met the needs of the decision-makers at the operational level. Therefore, the Decision Support Model was developed using some of the various methodologies outlined in these models as well as additional considerations based on personal experience in the Bioenvironmental and Civil Engineering fields.

The newly developed Model uses LCC Analysis as a means of evaluating the total LCC of using various materials. In evaluating the total LCC of a material, the Decision Support Model considers the following cost categories: Procurement, Transportation, Facility, Training, Handling, Personal Protection, Monitoring, Medical, Emergency Response, Disposal, Liability, and Intangible cost. These cost categories account for the costs associated with the "cradle-to-grave" management of hazardous materials over their entire life cycles.

This research also applied the newly developed Decision Support Model in a comprehensive case study involving an Air Force operation (Pathology Lab Tissue Processing). The case study demonstrates the use of the model in evaluating actual operations and clearly shows the potential cost savings associated with using various alternatives instead of hazardous materials currently being used in the tissue processing operations at Brooks AFB. As indicated in Table 10, the substitution of non-hazardous alternatives for baseline hazardous materials would result in a total annual cost savings of $93,274.63.

Table 10

Total Annual Savings

Material	Total Annual Cost	
10% Formalin (Baseline HM)	$78,208.81	
Normalin® (Alternative)	$291.69	
Annual Savings		**$77,917.12**
Clearing Agents (Baseline HM)	$16,722.51	
Slide-Brite® (Alternative)	$1,365.00	
Annual Savings		**$15,357.51**
Total Annual Savings		**$93,274.63**

VII. Insights

Implications

Due to recent budget cuts, the Air Force is concerned more than ever with reducing its operational costs while maintaining mission capability. One of the easiest ways to meet this goal is to use cost-effective alternatives for hazardous materials (i.e., materials with lower total life cycle costs). Even though the case study involved a relatively small Air Force operation, the annual cost savings associated with using alternatives for hazardous materials currently being used in this operation were over $93,000! In many cases, such as larger operations, the potential cost savings would be even greater. That is why it is important that managers, who use hazardous materials in their operations, have the necessary tools to evaluate various materials based on their total life cycle cost (LCC) instead of only considering a material's short-term costs (i.e., purchase cost). Therefore, the Decision Support Model could be used to justify the purchase of a "more expensive" material, in terms of its procurement cost, by demonstrating that it is less costly to the Air Force over its entire life cycle.

Another advantage of using the Decision Support Model is that the model helps to promote the goals of the Air Force's Pollution Prevention Program since the model usually selects materials that are less hazardous than those currently being used in Air Force operations. For example, as noted during the case study, less hazardous materials will usually have a lower total LCC than more hazardous materials because there are fewer regulatory requirements associated with the use of less hazardous materials.

Lastly, even though the model was tested specifically on an Air Force operation, its application is universal and could be used by other government and private-sector organizations. Since these organizations must follow the same regulatory requirements, the model will apply equally well.

Opportunities for Future Research

Although the decision support model is very useful in its present form, future research is needed to computerize the model. A computerized-version of this model would be useful in terms of performing many of the cost calculations and thus reducing the time currently required to perform tedious hand calculations.

Future research is also needed to develop a database that contains an up-to-date listing of the available alternatives for hazardous materials currently used in Air Force operations. With this listing, the users of this model could evaluate the economic feasibility of using various alternatives for baseline hazardous materials without performing extensive research to find suitable substitutes.

Appendix A

Inflation Tables

Table A45-1

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1988

FY	MILITARY COMPENSATION PAY BASE 3500	MILITARY COMPENSATION OTHER EXPEN 3500	MILITARY COMPENSATION TOTAL 3500	RETIRE-MENT 3500	GS & WB PAY 3400	O&M NON-PAY, NON-POL 3400	RDT&E 3600	MIL CON 3300	ACFT & MISSILE PROCURE-MENT 3010/20	OTHER PROCURE-MENT 3080	FUEL
1978	0.552	0.551	0.552	0.580	0.581	0.558	0.564	0.552	0.517	0.561	0.879
1979	0.585	0.595	0.587	0.628	0.616	0.609	0.611	0.605	0.562	0.609	1.017
1980	0.627	0.639	0.629	0.704	0.658	0.668	0.668	0.668	0.616	0.668	1.836
1981	0.726	0.793	0.735	0.783	0.715	0.748	0.748	0.748	0.689	0.748	2.174
1982	0.826	0.841	0.827	0.834	0.755	0.817	0.817	0.817	0.755	0.817	2.139
1983	0.859	0.87[illegible]	0.861	0.883	0.791	0.857	0.857	0.857	0.823	0.857	1.921
1984	0.884	0.904	0.887	0.913	0.815	0.889	0.889	0.889	0.889	0.889	1.744
1985	0.920	0.930	0.920	0.944	0.861	0.920	0.920	0.920	0.920	0.920	1.669
1986	0.956	0.952	0.956	0.950	0.870	0.945	0.945	0.945	0.945	0.945	1.304
1987	0.978	0.974	0.977	0.992	0.917	0.971	0.971	0.971	0.971	0.971	1.197
1988	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1989	1.036	1.034	1.036	1.016	1.035	1.042	1.042	1.042	1.042	1.042	1.001
1990	1.074	1.066	1.074	0.915	1.074	1.084	1.084	1.084	1.084	1.084	1.185
1991	1.117	1.103	1.116	0.939	1.116	1.130	1.130	1.130	1.130	1.130	2.218
1992	1.164	1.142	1.162	0.964	1.163	1.162	1.162	1.162	1.162	1.162	1.890
1993	1.208	1.178	1.205	0.856	1.207	1.190	1.190	1.190	1.190	1.190	2.071
1994	1.219	1.178	1.216	0.852	1.220	1.218	1.218	1.218	1.218	1.218	2.175
1995	1.238	1.198	1.234	0.852	1.238	1.246	1.246	1.246	1.246	1.246	2.286
1996	1.260	1.215	1.256	0.858	1.260	1.275	1.275	1.275	1.275	1.275	2.366
1997	1.280	1.232	1.276	0.864	1.280	1.303	1.303	1.303	1.303	1.303	2.449
1998	1.307	1.257	1.303	0.866	1.307	1.332	1.332	1.332	1.332	1.332	2.534
1999	1.337	1.282	1.332	0.870	1.337	1.361	1.361	1.361	1.361	1.361	2.623
2000	1.368	1.307	1.362	0.873	1.368	1.391	1.391	1.391	1.391	1.391	2.715
2001	1.400	1.333	1.393	0.877	1.399	1.422	1.422	1.422	1.422	1.422	2.810
2002	1.432	1.360	1.425	0.881	1.432	1.453	1.453	1.453	1.453	1.453	2.908
2003	1.465	1.387	1.457	0.884	1.465	1.485	1.485	1.485	1.485	1.485	3.010
2004	1.498	1.415	1.490	0.888	1.498	1.518	1.518	1.518	1.518	1.518	3.115
2005	1.533	1.443	1.524	0.892	1.533	1.551	1.551	1.551	1.551	1.551	3.224
2006	1.568	1.472	1.559	0.895	1.568	1.585	1.585	1.585	1.585	1.585	3.337
2007	1.604	1.501	1.594	0.899	1.604	1.620	1.620	1.620	1.620	1.620	3.454
2008	1.641	1.531	1.630	0.903	1.641	1.656	1.656	1.656	1.656	1.656	3.575

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DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

Table A45-2

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1989

FY	MILITARY COMPENSATION PAY BASE 3500	OTHER EXPEN 3500	TOTAL 3500	RETIRE-MENT 3500	GS & WB PAY 3400	O&M NON-PAY, NON-POL 3400	RDT&E 3600	MIL CON 3300	ACFT & MISSILE PROCURE-MENT 3010/20	OTHER PROCURE-MENT 3080	FUEL
1978	0.533	0.533	0.533	0.571	0.561	0.536	0.541	0.530	0.496	0.538	0.879
1979	0.565	0.575	0.567	0.618	0.595	0.585	0.586	0.581	0.539	0.585	1.016
1980	0.605	0.618	0.607	0.693	0.636	0.641	0.641	0.641	0.591	0.641	1.834
1981	0.701	0.767	0.710	0.770	0.691	0.718	0.718	0.718	0.662	0.718	2.172
1982	0.797	0.813	0.799	0.821	0.730	0.784	0.784	0.784	0.725	0.784	2.137
1983	0.829	0.847	0.831	0.868	0.764	0.822	0.822	0.822	0.790	0.822	1.919
1984	0.854	0.874	0.856	0.898	0.788	0.854	0.854	0.854	0.854	0.854	1.743
1985	0.888	0.900	0.889	0.929	0.832	0.883	0.883	0.883	0.883	0.883	1.668
1986	0.923	0.921	0.923	0.935	0.840	0.907	0.907	0.907	0.907	0.907	1.302
1987	0.944	0.942	0.944	0.976	0.886	0.932	0.932	0.932	0.932	0.932	1.196
1988	0.965	0.967	0.966	0.984	0.966	0.960	0.960	0.960	0.960	0.960	0.999
1989	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1990	1.037	1.031	1.037	0.901	1.037	1.040	1.040	1.040	1.040	1.040	1.184
1991	1.078	1.067	1.077	0.924	1.078	1.085	1.085	1.085	1.085	1.085	2.216
1992	1.124	1.105	1.122	0.949	1.123	1.115	1.115	1.115	1.115	1.115	1.888
1993	1.166	1.139	1.164	0.842	1.167	1.142	1.142	1.142	1.142	1.142	2.070
1994	1.177	1.139	1.174	0.838	1.179	1.169	1.169	1.169	1.169	1.169	2.173
1995	1.195	1.159	1.192	0.839	1.196	1.196	1.196	1.196	1.196	1.196	2.284
1996	1.216	1.175	1.213	0.844	1.217	1.224	1.224	1.224	1.224	1.224	2.364
1997	1.236	1.191	1.232	0.850	1.237	1.251	1.251	1.251	1.251	1.251	2.447
1998	1.262	1.215	1.258	0.852	1.263	1.278	1.278	1.278	1.278	1.278	2.532
1999	1.291	1.239	1.287	0.856	1.292	1.306	1.306	1.306	1.306	1.306	2.621
2000	1.321	1.264	1.316	0.859	1.322	1.335	1.335	1.335	1.335	1.335	2.713
2001	1.351	1.289	1.346	0.863	1.352	1.364	1.364	1.364	1.364	1.364	2.808
2002	1.382	1.315	1.376	0.866	1.383	1.394	1.394	1.394	1.394	1.394	2.906
2003	1.414	1.341	1.407	0.870	1.415	1.425	1.425	1.425	1.425	1.425	3.008
2004	1.447	1.368	1.439	0.874	1.448	1.456	1.456	1.456	1.456	1.456	3.113
2005	1.480	1.395	1.472	0.877	1.481	1.488	1.488	1.488	1.488	1.488	3.222
2006	1.514	1.423	1.505	0.881	1.515	1.521	1.521	1.521	1.521	1.521	3.335
2007	1.549	1.452	1.540	0.885	1.550	1.555	1.555	1.555	1.555	1.555	3.451
2008	1.584	1.481	1.575	0.888	1.586	1.589	1.589	1.589	1.589	1.589	3.572

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DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1990

FY	MILITARY COMPENSATION PAY BASE 3500	OTHER EXPEN 3500	TOTAL 3500	RETIRE-MENT 3500	GS & WB PAY 3400	O&M NON-PAY, NON-POL 3400	RDT&E 3600	MIL CON 3300	ACFT & MISSILE PROCURE-MENT 3010/20	OTHER PROCURE-MENT 3080	FUEL
1978	0.514	0.517	0.515	0.634	0.541	0.515	0.520	0.510	0.477	0.517	0.742
1979	0.544	0.558	0.547	0.686	0.574	0.562	0.564	0.559	0.518	0.562	0.858
1980	0.583	0.599	0.586	0.769	0.613	0.617	0.617	0.617	0.568	0.617	1.549
1981	0.676	0.744	0.685	0.855	0.666	0.690	0.690	0.690	0.636	0.690	1.834
1982	0.768	0.789	0.771	0.912	0.704	0.754	0.754	0.754	0.697	0.754	1.805
1983	0.799	0.822	0.802	0.964	0.736	0.791	0.791	0.791	0.760	0.791	1.621
1984	0.823	0.848	0.826	0.997	0.759	0.821	0.821	0.821	0.821	0.821	1.472
1985	0.856	0.873	0.857	1.032	0.802	0.849	0.849	0.849	0.849	0.849	1.409
1986	0.890	0.894	0.890	1.038	0.810	0.872	0.872	0.872	0.872	0.872	1.100
1987	0.910	0.914	0.910	1.084	0.854	0.896	0.896	0.896	0.896	0.896	1.010
1988	0.931	0.938	0.932	1.093	0.931	0.923	0.923	0.923	0.923	0.923	0.844
1989	0.964	0.970	0.965	1.110	0.964	0.962	0.962	0.962	0.962	0.962	0.845
1990	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1991	1.040	1.035	1.039	1.026	1.040	1.043	1.043	1.043	1.043	1.043	1.872
1992	1.083	1.072	1.082	1.054	1.083	1.072	1.072	1.072	1.072	1.072	1.595
1993	1.125	1.106	1.123	0.935	1.125	1.098	1.098	1.098	1.098	1.098	1.748
1994	1.135	1.106	1.132	0.931	1.137	1.124	1.124	1.124	1.124	1.124	1.835
1995	1.152	1.124	1.150	0.931	1.153	1.150	1.150	1.150	1.150	1.150	1.929
1996	1.172	1.141	1.170	0.937	1.173	1.177	1.177	1.177	1.177	1.177	1.997
1997	1.192	1.156	1.188	0.944	1.192	1.202	1.202	1.202	1.202	1.202	2.066
1998	1.217	1.179	1.213	0.946	1.217	1.229	1.229	1.229	1.229	1.229	2.139
1999	1.245	1.203	1.241	0.950	1.245	1.256	1.256	1.256	1.256	1.256	2.214
2000	1.273	1.227	1.269	0.954	1.274	1.284	1.284	1.284	1.284	1.284	2.291
2001	1.303	1.251	1.298	0.958	1.303	1.312	1.312	1.312	1.312	1.312	2.371
2002	1.333	1.276	1.327	0.962	1.333	1.341	1.341	1.341	1.341	1.341	2.454
2003	1.363	1.302	1.358	0.966	1.364	1.370	1.370	1.370	1.370	1.370	2.540
2004	1.395	1.327	1.388	0.970	1.395	1.400	1.400	1.400	1.400	1.400	2.629
2005	1.427	1.354	1.420	0.974	1.428	1.431	1.431	1.431	1.431	1.431	2.721
2006	1.460	1.381	1.452	0.978	1.460	1.463	1.463	1.463	1.463	1.463	2.816
2007	1.493	1.409	1.485	0.982	1.494	1.495	1.495	1.495	1.495	1.495	2.915
2008	1.528	1.437	1.519	0.986	1.528	1.528	1.528	1.528	1.528	1.528	3.017

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Table A45-4

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1991

	MILITARY COMPENSATION					O&M			ACFT &		
	PAY	OTHER		RETIRE-	GS &	NON-PAY,		MIL	MISSILE PROCURE-	OTHER PROCURE-	
	BASE	EXPEN	TOTAL	MENT	WB PAY	NON-POL	RDT&E	CON	MENT	MENT	
FY	3500	3500	3500	3500	3400	3400	3600	3300	3010/20	3080	FUEL
1978	0.494	0.500	0.495	0.618	0.520	0.494	0.499	0.489	0.457	0.496	0.396
1979	0.524	0.539	0.526	0.669	0.552	0.539	0.541	0.536	0.497	0.539	0.458
1980	0.561	0.579	0.563	0.750	0.590	0.591	0.591	0.591	0.545	0.591	0.828
1981	0.650	0.719	0.659	0.834	0.641	0.662	0.662	0.662	0.610	0.662	0.980
1982	0.739	0.762	0.742	0.889	0.677	0.723	0.723	0.723	0.668	0.723	0.964
1983	0.769	0.794	0.772	0.940	0.708	0.758	0.758	0.758	0.729	0.758	0.866
1984	0.792	0.820	0.795	0.972	0.730	0.787	0.787	0.787	0.787	0.787	0.786
1985	0.823	0.844	0.825	1.006	0.771	0.814	0.814	0.814	0.814	0.814	0.752
1986	0.856	0.864	0.857	1.012	0.779	0.836	0.836	0.836	0.836	0.836	0.588
1987	0.876	0.883	0.876	1.057	0.822	0.859	0.859	0.859	0.859	0.859	0.540
1988	0.895	0.907	0.896	1.065	0.896	0.885	0.885	0.885	0.885	0.885	0.451
1989	0.927	0.938	0.928	1.083	0.927	0.922	0.922	0.922	0.922	0.922	0.451
1990	0.962	0.966	0.962	0.975	0.962	0.959	0.959	0.959	0.959	0.959	0.534
1991	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1992	1.042	1.036	1.041	1.027	1.042	1.028	1.028	1.028	1.028	1.028	0.852
1993	1.082	1.068	1.080	0.912	1.082	1.053	1.053	1.053	1.053	1.053	0.934
1994	1.092	1.068	1.090	0.907	1.093	1.078	1.078	1.078	1.078	1.078	0.980
1995	1.108	1.086	1.106	0.908	1.109	1.103	1.103	1.103	1.103	1.103	1.030
1996	1.128	1.102	1.125	0.914	1.129	1.128	1.128	1.128	1.128	1.128	1.067
1997	1.146	1.117	1.143	0.921	1.147	1.153	1.153	1.153	1.153	1.153	1.104
1998	1.170	1.139	1.168	0.923	1.171	1.178	1.178	1.178	1.178	1.178	1.143
1999	1.197	1.162	1.194	0.927	1.198	1.204	1.204	1.204	1.204	1.204	1.183
2000	1.225	1.185	1.221	0.930	1.226	1.231	1.231	1.231	1.231	1.231	1.224
2001	1.253	1.209	1.249	0.934	1.254	1.258	1.258	1.258	1.258	1.258	1.267
2002	1.282	1.233	1.277	0.938	1.283	1.285	1.285	1.285	1.285	1.285	1.311
2003	1.311	1.258	1.306	0.942	1.312	1.314	1.314	1.314	1.314	1.314	1.357
2004	1.341	1.283	1.336	0.946	1.342	1.343	1.343	1.343	1.343	1.343	1.404
2005	1.372	1.308	1.366	0.950	1.373	1.372	1.372	1.372	1.372	1.372	1.454
2006	1.404	1.334	1.397	0.954	1.405	1.402	1.402	1.402	1.402	1.402	1.504
2007	1.436	1.361	1.429	0.958	1.437	1.433	1.433	1.433	1.433	1.433	1.557
2008	1.469	1.388	1.461	0.962	1.470	1.465	1.465	1.465	1.465	1.465	1.612

OPR: SAF/FMCE, DSN: 227-9347
DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

Table A45-5

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1992

	MILITARY COMPENSATION										
FY	PAY BASE 3500	OTHER EXPEN 3500	TOTAL 3500	RETIRE-MENT 3500	GS & WB PAY 3400	O&M NON-PAY, NON-POL 3400	RDT&E 3600	MIL CON 3300	ACFT & MISSILE PROCURE-MENT 3010/20	OTHER PROCURE-MENT 3080	FUEL
1978	0.474	0.483	0.476	0.602	0.500	0.481	0.485	0.475	0.445	0.482	0.465
1979	0.503	0.521	0.505	0.651	0.530	0.524	0.526	0.521	0.483	0.524	0.538
1980	0.539	0.559	0.541	0.730	0.566	0.575	0.575	0.575	0.530	0.575	0.971
1981	0.624	0.694	0.633	0.812	0.615	0.644	0.644	0.644	0.593	0.644	1.150
1982	0.709	0.736	0.712	0.865	0.650	0.703	0.703	0.703	0.650	0.703	1.132
1983	0.738	0.767	0.741	0.915	0.680	0.737	0.737	0.737	0.709	0.737	1.016
1984	0.760	0.792	0.763	0.946	0.701	0.765	0.765	0.765	0.765	0.765	0.923
1985	0.790	0.814	0.792	0.980	0.741	0.791	0.791	0.791	0.791	0.791	0.883
1986	0.822	0.834	0.823	0.985	0.748	0.814	0.814	0.814	0.814	0.814	0.690
1987	0.840	0.853	0.841	1.029	0.789	0.836	0.836	0.836	0.836	0.836	0.633
1988	0.859	0.876	0.861	1.037	0.860	0.861	0.861	0.861	0.861	0.861	0.529
1989	0.890	0.905	0.891	1.054	0.890	0.897	0.897	0.897	0.897	0.897	0.530
1990	0.923	0.933	0.924	0.949	0.923	0.933	0.933	0.933	0.933	0.933	0.627
1991	0.960	0.966	0.960	0.973	0.960	0.973	0.973	0.973	0.973	0.973	1.174
1992	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1993	1.038	1.031	1.038	0.887	1.038	1.024	1.024	1.024	1.024	1.024	1.096
1994	1.048	1.031	1.046	0.883	1.050	1.049	1.049	1.049	1.049	1.049	1.151
1995	1.064	1.049	1.062	0.884	1.064	1.073	1.073	1.073	1.073	1.073	1.209
1996	1.082	1.064	1.081	0.890	1.084	1.097	1.097	1.097	1.097	1.097	1.252
1997	1.100	1.079	1.098	0.896	1.101	1.122	1.122	1.122	1.122	1.122	1.296
1998	1.123	1.100	1.121	0.898	1.124	1.146	1.146	1.146	1.146	1.146	1.341
1999	1.149	1.122	1.147	0.902	1.150	1.171	1.171	1.171	1.171	1.171	1.388
2000	1.176	1.144	1.173	0.906	1.177	1.197	1.197	1.197	1.197	1.197	1.436
2001	1.203	1.167	1.199	0.909	1.204	1.224	1.224	1.224	1.224	1.224	1.487
2002	1.230	1.191	1.227	0.913	1.231	1.250	1.250	1.250	1.250	1.250	1.539
2003	1.259	1.214	1.254	0.917	1.260	1.278	1.278	1.278	1.278	1.278	1.593
2004	1.288	1.239	1.283	0.921	1.289	1.306	1.306	1.306	1.306	1.306	1.648
2005	1.317	1.263	1.312	0.925	1.318	1.335	1.335	1.335	1.335	1.335	1.706
2006	1.348	1.288	1.342	0.929	1.349	1.364	1.364	1.364	1.364	1.364	1.766
2007	1.379	1.314	1.372	0.932	1.380	1.394	1.394	1.394	1.394	1.394	1.828
2008	1.410	1.340	1.403	0.936	1.411	1.425	1.425	1.425	1.425	1.425	1.892

OPR: SAF/FMCE, DSN: 227-9347
DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1993

	MILITARY COMPENSATION					O&M			ACFT &	OTHER	
	PAY BASE	OTHER EXPEN	TOTAL	RETIRE-MENT	GS & WB PAY	NON-PAY, NON-POL	RDT&E	MIL CON	MISSILE PROCURE-MENT	PROCURE-MENT	
FY	3500	3500	3500	3500	3400	3400	3600	3300	3010/20	3080	FUEL
1978	0.457	0.468	0.458	0.678	0.481	0.469	0.474	0.464	0.434	0.471	0.425
1979	0.484	0.505	0.487	0.734	0.510	0.512	0.514	0.509	0.472	0.512	0.491
1980	0.519	0.542	0.521	0.823	0.545	0.562	0.562	0.562	0.518	0.562	0.886
1981	0.601	0.673	0.610	0.915	0.592	0.629	0.629	0.629	0.579	0.629	1.049
1982	0.683	0.714	0.686	0.975	0.626	0.686	0.686	0.686	0.635	0.686	1.033
1983	0.711	0.743	0.714	1.031	0.655	0.720	0.720	0.720	0.692	0.720	0.927
1984	0.732	0.767	0.736	1.066	0.675	0.747	0.747	0.747	0.747	0.747	0.842
1985	0.761	0.790	0.763	1.104	0.713	0.773	0.773	0.773	0.773	0.773	0.806
1986	0.792	0.808	0.793	1.110	0.720	0.795	0.795	0.795	0.795	0.795	0.629
1987	0.809	0.827	0.811	1.159	0.759	0.816	0.816	0.816	0.816	0.816	0.578
1988	0.828	0.849	0.830	1.169	0.828	0.840	0.840	0.840	0.840	0.840	0.483
1989	0.857	0.878	0.859	1.188	0.857	0.876	0.876	0.876	0.876	0.876	0.483
1990	0.889	0.905	0.891	1.069	0.889	0.911	0.911	0.911	0.911	0.911	0.572
1991	0.925	0.936	0.926	1.097	0.924	0.950	0.950	0.950	0.950	0.950	1.071
1992	0.963	0.970	0.964	1.127	0.963	0.977	0.977	0.977	0.977	0.977	0.912
1993	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1994	1.009	1.000	1.008	0.995	1.011	1.024	1.024	1.024	1.024	1.024	1.050
1995	1.024	1.017	1.024	0.996	1.025	1.048	1.048	1.048	1.048	1.048	1.104
1996	1.043	1.032	1.042	1.002	1.043	1.072	1.072	1.072	1.072	1.072	1.142
1997	1.060	1.046	1.058	1.010	1.060	1.095	1.095	1.095	1.095	1.095	1.182
1998	1.082	1.067	1.081	1.012	1.083	1.119	1.119	1.119	1.119	1.119	1.224
1999	1.107	1.088	1.105	1.016	1.108	1.144	1.144	1.144	1.144	1.144	1.266
2000	1.132	1.110	1.130	1.020	1.133	1.169	1.169	1.169	1.169	1.169	1.311
2001	1.158	1.132	1.156	1.025	1.159	1.195	1.195	1.195	1.195	1.195	1.357
2002	1.185	1.154	1.182	1.029	1.186	1.221	1.221	1.221	1.221	1.221	1.404
2003	1.212	1.177	1.209	1.033	1.213	1.248	1.248	1.248	1.248	1.248	1.453
2004	1.240	1.201	1.236	1.038	1.241	1.275	1.275	1.275	1.275	1.275	1.504
2005	1.269	1.225	1.264	1.042	1.269	1.303	1.303	1.303	1.303	1.303	1.557
2006	1.298	1.249	1.293	1.046	1.299	1.332	1.332	1.332	1.332	1.332	1.611
2007	1.328	1.274	1.323	1.051	1.329	1.361	1.361	1.361	1.361	1.361	1.668
2008	1.358	1.300	1.353	1.055	1.359	1.391	1.391	1.391	1.391	1.391	1.726

OPR: SAF/FMCE, DSN: 227-9347
DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

Table A45-7

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1994

FY	MILITARY COMPENSATION PAY BASE 3500	MILITARY COMPENSATION OTHER EXPEN 3500	MILITARY COMPENSATION TOTAL 3500	MILITARY COMPENSATION RETIRE-MENT 3500	GS & WB PAY 3400	O&M NON-PAY, NON-POL 3400	RDT&E 3600	MIL CON 3300	ACFT & MISSILE PROCURE-MENT 3010/20	OTHER PROCURE-MENT 3080	FUEL
1978	0.453	0.468	0.454	0.681	0.476	0.458	0.463	0.453	0.424	0.460	0.404
1979	0.480	0.505	0.483	0.737	0.505	0.500	0.501	0.497	0.461	0.500	0.467
1980	0.514	0.542	0.517	0.827	0.539	0.549	0.549	0.549	0.506	0.549	0.844
1981	0.595	0.673	0.605	0.919	0.586	0.614	0.614	0.614	0.566	0.614	0.999
1982	0.677	0.714	0.681	0.980	0.619	0.670	0.670	0.670	0.620	0.670	0.983
1983	0.704	0.743	0.708	1.036	0.648	0.703	0.703	0.703	0.676	0.703	0.883
1984	0.725	0.767	0.730	1.072	0.668	0.730	0.730	0.730	0.730	0.730	0.802
1985	0.754	0.790	0.757	1.109	0.706	0.755	0.755	0.755	0.755	0.755	0.767
1986	0.784	0.808	0.786	1.116	0.713	0.776	0.776	0.776	0.776	0.776	0.599
1987	0.802	0.827	0.804	1.165	0.751	0.797	0.797	0.797	0.797	0.797	0.550
1988	0.820	0.849	0.823	1.174	0.819	0.821	0.821	0.821	0.821	0.821	0.460
1989	0.849	0.878	0.852	1.193	0.848	0.855	0.855	0.855	0.855	0.855	0.460
1990	0.881	0.905	0.883	1.075	0.880	0.889	0.889	0.889	0.889	0.889	0.545
1991	0.916	0.936	0.918	1.102	0.915	0.928	0.928	0.928	0.928	0.928	1.020
1992	0.954	0.970	0.956	1.132	0.953	0.954	0.954	0.954	0.954	0.954	0.869
1993	0.991	1.000	0.992	1.005	0.989	0.977	0.977	0.977	0.977	0.977	0.952
1994	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1995	1.015	1.017	1.015	1.001	1.014	1.023	1.023	1.023	1.023	1.023	1.051
1996	1.033	1.032	1.033	1.007	1.032	1.047	1.047	1.047	1.047	1.047	1.088
1997	1.050	1.046	1.049	1.015	1.049	1.070	1.070	1.070	1.070	1.070	1.126
1998	1.072	1.067	1.072	1.017	1.071	1.093	1.093	1.093	1.093	1.093	1.165
1999	1.097	1.088	1.096	1.021	1.096	1.117	1.117	1.117	1.117	1.117	1.206
2000	1.122	1.110	1.121	1.025	1.121	1.142	1.142	1.142	1.142	1.142	1.248
2001	1.148	1.132	1.146	1.030	1.147	1.167	1.167	1.167	1.167	1.167	1.292
2002	1.174	1.154	1.172	1.034	1.173	1.192	1.192	1.192	1.192	1.192	1.337
2003	1.201	1.177	1.199	1.038	1.200	1.219	1.219	1.219	1.219	1.219	1.384
2004	1.229	1.201	1.226	1.043	1.228	1.246	1.246	1.246	1.246	1.246	1.432
2005	1.257	1.225	1.254	1.047	1.256	1.273	1.273	1.273	1.273	1.273	1.483
2006	1.286	1.249	1.282	1.051	1.285	1.301	1.301	1.301	1.301	1.301	1.534
2007	1.316	1.274	1.311	1.056	1.314	1.330	1.330	1.330	1.330	1.330	1.588
2008	1.346	1.300	1.341	1.060	1.345	1.359	1.359	1.359	1.359	1.359	1.644

OPR: SAF/FMCE, DSN: 227-9347
DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1995

	MILITARY COMPENSATION					O&M			ACFT & MISSILE	OTHER	
FY	PAY BASE 3500	OTHER EXPEN 3500	TOTAL 3500	RETIREMENT 3500	GS & WB PAY 3400	NON-PAY, NON-POL 3400	RDT&E 3600	MIL CON 3300	PROCUREMENT 3010/20	PROCUREMENT 3080	FUEL
1978	0.446	0.460	0.448	0.681	0.469	0.448	0.452	0.443	0.414	0.450	0.385
1979	0.473	0.497	0.475	0.737	0.498	0.489	0.490	0.486	0.451	0.489	0.445
1980	0.506	0.533	0.509	0.826	0.532	0.536	0.536	0.536	0.494	0.536	0.803
1981	0.587	0.662	0.596	0.918	0.578	0.600	0.600	0.600	0.553	0.600	0.951
1982	0.667	0.702	0.671	0.979	0.610	0.655	0.655	0.655	0.606	0.655	0.936
1983	0.694	0.731	0.698	1.035	0.639	0.687	0.687	0.687	0.661	0.687	0.840
1984	0.715	0.755	0.719	1.071	0.659	0.714	0.714	0.714	0.714	0.714	0.763
1985	0.743	0.776	0.746	1.108	0.696	0.738	0.738	0.738	0.738	0.738	0.730
1986	0.773	0.795	0.774	1.115	0.703	0.758	0.758	0.758	0.758	0.758	0.570
1987	0.790	0.813	0.792	1.164	0.741	0.779	0.779	0.779	0.779	0.779	0.524
1988	0.808	0.835	0.810	1.173	0.808	0.802	0.802	0.802	0.802	0.802	0.437
1989	0.837	0.863	0.839	1.192	0.836	0.836	0.836	0.836	0.836	0.836	0.438
1990	0.868	0.889	0.870	1.074	0.868	0.869	0.869	0.869	0.869	0.869	0.518
1991	0.903	0.920	0.904	1.101	0.902	0.907	0.907	0.907	0.907	0.907	0.970
1992	0.940	0.953	0.941	1.131	0.939	0.932	0.932	0.932	0.932	0.932	0.827
1993	0.976	0.983	0.977	1.004	0.976	0.955	0.955	0.955	0.955	0.955	0.906
1994	0.985	0.983	0.985	0.999	0.986	0.978	0.978	0.978	0.978	0.978	0.951
1995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	1.018	1.014	1.017	1.006	1.018	1.023	1.023	1.023	1.023	1.023	1.035
1997	1.034	1.028	1.034	1.014	1.034	1.046	1.046	1.046	1.046	1.046	1.071
1998	1.056	1.049	1.056	1.016	1.056	1.069	1.069	1.069	1.069	1.069	1.109
1999	1.081	1.070	1.080	1.020	1.080	1.092	1.092	1.092	1.092	1.092	1.148
2000	1.105	1.091	1.104	1.024	1.105	1.116	1.116	1.116	1.116	1.116	1.188
2001	1.131	1.113	1.129	1.029	1.131	1.141	1.141	1.141	1.141	1.141	1.229
2002	1.157	1.135	1.155	1.033	1.157	1.166	1.166	1.166	1.166	1.166	1.272
2003	1.183	1.158	1.181	1.037	1.183	1.191	1.191	1.191	1.191	1.191	1.317
2004	1.211	1.181	1.208	1.042	1.211	1.218	1.218	1.218	1.218	1.218	1.363
2005	1.239	1.204	1.235	1.046	1.238	1.244	1.244	1.244	1.244	1.244	1.411
2006	1.267	1.228	1.263	1.050	1.267	1.272	1.272	1.272	1.272	1.272	1.460
2007	1.296	1.253	1.292	1.055	1.296	1.300	1.300	1.300	1.300	1.300	1.511
2008	1.326	1.278	1.321	1.059	1.326	1.328	1.328	1.328	1.328	1.328	1.564

OPR: SAF/FMCE, DSN: 227-9347
DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1996

FY	MILITARY COMPENSATION PAY BASE 3500	OTHER EXPEN 3500	TOTAL 3500	RETIRE-MENT 3500	GS & WB PAY 3400	O&M NON-PAY, NON-POL 3400	RDT&E 3600	MIL CON 3300	ACFT & MISSILE PROCURE-MENT 3010/20	OTHER PROCURE-MENT 3080	FUEL
1978	0.438	0.454	0.440	0.676	0.461	0.438	0.442	0.433	0.405	0.440	0.372
1979	0.464	0.489	0.467	0.732	0.489	0.478	0.479	0.475	0.440	0.478	0.430
1980	0.498	0.526	0.501	0.821	0.522	0.524	0.524	0.524	0.483	0.524	0.776
1981	0.576	0.652	0.585	0.913	0.568	0.587	0.587	0.587	0.541	0.587	0.919
1982	0.655	0.692	0.659	0.973	0.600	0.641	0.641	0.641	0.593	0.641	0.904
1983	0.682	0.721	0.686	1.029	0.628	0.672	0.672	0.672	0.646	0.672	0.812
1984	0.702	0.744	0.706	1.064	0.647	0.698	0.698	0.698	0.698	0.698	0.737
1985	0.730	0.765	0.733	1.101	0.683	0.721	0.721	0.721	0.721	0.721	0.705
1986	0.759	0.784	0.761	1.108	0.690	0.741	0.741	0.741	0.741	0.741	0.551
1987	0.776	0.802	0.778	1.157	0.728	0.761	0.761	0.761	0.761	0.761	0.506
1988	0.794	0.823	0.796	1.166	0.794	0.784	0.784	0.784	0.784	0.784	0.423
1989	0.822	0.851	0.825	1.185	0.821	0.817	0.817	0.817	0.817	0.817	0.423
1990	0.853	0.877	0.855	1.067	0.852	0.850	0.850	0.850	0.850	0.850	0.501
1991	0.887	0.907	0.889	1.094	0.886	0.886	0.886	0.886	0.886	0.886	0.938
1992	0.924	0.940	0.925	1.124	0.923	0.911	0.911	0.911	0.911	0.911	0.799
1993	0.959	0.969	0.960	0.998	0.958	0.933	0.933	0.933	0.933	0.933	0.876
1994	0.968	0.969	0.968	0.993	0.969	0.956	0.956	0.956	0.956	0.956	0.919
1995	0.983	0.986	0.983	0.994	0.982	0.978	0.978	0.978	0.978	0.978	0.966
1996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1997	1.016	1.014	1.016	1.008	1.016	1.022	1.022	1.022	1.022	1.022	1.035
1998	1.038	1.034	1.037	1.010	1.038	1.044	1.044	1.044	1.044	1.044	1.071
1999	1.062	1.054	1.061	1.014	1.061	1.067	1.067	1.067	1.067	1.067	1.109
2000	1.086	1.075	1.085	1.018	1.086	1.091	1.091	1.091	1.091	1.091	1.148
2001	1.111	1.097	1.110	1.022	1.111	1.115	1.115	1.115	1.115	1.115	1.188
2002	1.137	1.119	1.135	1.027	1.136	1.139	1.139	1.139	1.139	1.139	1.229
2003	1.163	1.141	1.161	1.031	1.163	1.165	1.165	1.165	1.165	1.165	1.272
2004	1.190	1.164	1.187	1.035	1.189	1.190	1.190	1.190	1.190	1.190	1.317
2005	1.217	1.187	1.214	1.040	1.217	1.216	1.216	1.216	1.216	1.216	1.363
2006	1.245	1.211	1.242	1.044	1.245	1.243	1.243	1.243	1.243	1.243	1.411
2007	1.274	1.235	1.270	1.048	1.273	1.270	1.270	1.270	1.270	1.270	1.460
2008	1.303	1.260	1.299	1.053	1.303	1.298	1.298	1.298	1.298	1.298	1.511

OPR: SAF/FMCE, DSN: 227-9347
DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

USAF RAW INFLATION INDICES
BASED ON OSD RAW INFLATION RATES
BASE YEAR FY 1997

FY	MILITARY COMPENSATION PAY BASE 3500	OTHER EXPEN 3500	TOTAL 3500	RETIRE-MENT 3500	GS & WB PAY 3400	O&M NON-PAY, NON-POL 3400	RDT&E 3600	MIL CON 3300	ACFT & MISSILE PROCURE-MENT 3010/20	OTHER PROCURE-MENT 3080	FUEL
1978	0.431	0.447	0.433	0.671	0.454	0.429	0.433	0.424	0.396	0.430	0.359
1979	0.457	0.483	0.460	0.727	0.481	0.468	0.469	0.465	0.431	0.468	0.415
1980	0.490	0.519	0.493	0.815	0.514	0.513	0.513	0.513	0.473	0.513	0.750
1981	0.567	0.643	0.576	0.906	0.559	0.574	0.574	0.574	0.529	0.574	0.888
1982	0.645	0.682	0.649	0.965	0.590	0.627	0.627	0.627	0.580	0.627	0.873
1983	0.671	0.711	0.675	1.021	0.618	0.658	0.658	0.658	0.632	0.658	0.784
1984	0.691	0.734	0.695	1.056	0.637	0.682	0.682	0.682	0.682	0.682	0.712
1985	0.718	0.755	0.721	1.093	0.673	0.706	0.706	0.706	0.706	0.706	0.682
1986	0.747	0.773	0.749	1.099	0.679	0.725	0.725	0.725	0.725	0.725	0.532
1987	0.764	0.791	0.766	1.148	0.716	0.745	0.745	0.745	0.745	0.745	0.489
1988	0.781	0.812	0.784	1.157	0.781	0.767	0.767	0.767	0.767	0.767	0.408
1989	0.809	0.839	0.812	1.176	0.808	0.800	0.800	0.800	0.800	0.800	0.409
1990	0.839	0.865	0.842	1.059	0.839	0.832	0.832	0.832	0.832	0.832	0.484
1991	0.873	0.895	0.875	1.086	0.872	0.867	0.867	0.867	0.867	0.867	0.906
1992	0.909	0.927	0.911	1.116	0.908	0.892	0.892	0.892	0.892	0.892	0.772
1993	0.944	0.956	0.945	0.990	0.943	0.913	0.913	0.913	0.913	0.913	0.846
1994	0.953	0.956	0.953	0.985	0.953	0.935	0.935	0.935	0.935	0.935	0.888
1995	0.967	0.973	0.967	0.986	0.967	0.956	0.956	0.956	0.956	0.956	0.934
1996	0.984	0.987	0.984	0.992	0.984	0.978	0.978	0.978	0.978	0.978	0.966
1997	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1998	1.021	1.020	1.021	1.002	1.021	1.022	1.022	1.022	1.022	1.022	1.035
1999	1.045	1.040	1.044	1.006	1.044	1.044	1.044	1.044	1.044	1.044	1.071
2000	1.069	1.061	1.068	1.010	1.068	1.067	1.067	1.067	1.067	1.067	1.109
2001	1.093	1.082	1.092	1.015	1.093	1.091	1.091	1.091	1.091	1.091	1.148
2002	1.118	1.104	1.117	1.019	1.118	1.115	1.115	1.115	1.115	1.115	1.188
2003	1.144	1.126	1.142	1.023	1.144	1.139	1.139	1.139	1.139	1.139	1.229
2004	1.171	1.148	1.168	1.027	1.170	1.165	1.165	1.165	1.165	1.165	1.272
2005	1.197	1.171	1.195	1.032	1.197	1.190	1.190	1.190	1.190	1.190	1.317
2006	1.225	1.195	1.222	1.036	1.225	1.216	1.216	1.216	1.216	1.216	1.363
2007	1.253	1.218	1.250	1.040	1.253	1.243	1.243	1.243	1.243	1.243	1.411
2008	1.282	1.243	1.278	1.045	1.282	1.270	1.270	1.270	1.270	1.270	1.460

OPR: SAF/FMCE, DSN: 227-9347
DATE OF OSD INFLATION RATES FOR PERSONNEL : 3 MARCH 1993
DATE OF OSD INFLATION RATES FOR NON-PERSONNEL : 3 MARCH 1993

Appendix B

Present Value Analysis

Appendix B

Present Value Analysis
(1:91-94)

While this paper does not allow for a complete treatise of the time value of money, it is useful to review the basics of the concept of present value analysis.[1] The importance of present value analysis lies in the fact that time is money. What is the preference between a dollar now or a dollar a year from now? Obviously, the dollar in hand is preferred because it could earn interest. Because money can "work," at 5% interest, there is no difference between $.95 now and $1.00 in one year because they both have the same value at the present time.[2] Mathematically, this relationship is as follows:

$$P = \frac{F}{(1 + r)^n}$$

where P is the present value, F is the future value, r is the interest (or discount) rate, and n is the number of periods. In the above example, $1 in one year at 5% interest would have a computed present value of:

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1. For a more complete review including equal payment series, future value, etc., the reader is referred to any of a number of accounting texts such as Davidson, Stickney, and Weil, <u>Financial Accounting, An Introduction to concepts, Methods, and Uses</u>, Fifth Edition, Harcourt Brace Jovanovich, Publishers, 1988.

2. Economically, there is an additional factor at work in present value: pure time preference (or impatience) - Pearce and Turner, <u>Economics of Natural Resources and the Environment</u>, 1977, pg 213. However, this issue is generally ignored in business accounting in that the firm has no such emotions and opportunities can be measured in terms of pure financial return.

$$P = \frac{\$1.00}{(1 + 0.05)^1} = \$0.95$$

Similarly, if the $1 was to be received in 3 years, the present value would be:

$$P = \frac{\$1.00}{(1 + 0.05)^3} = \$0.86$$

In looking at either multiple payments or cash both into and out of a firm, the present values are additive. For example, at 5% interest, the present value of both $1 in one year and an additional $1 in 3 years would be $0.95 + $0.86 = $1.81. Similarly, if one was to receive $1 in one year, and pay $1 in 3 years the present value would be $0.95 - $0.86 = $0.09. This allows both costs and benefits which are expended or earned in the future to be expressed at their current or present value.

<u>The Effects of Interest/Discount Rates</u>

In determining the present value of costs occurring in later years, the discount rate used becomes critical. If costs are expended far into the future, or if a larger discount rate is used, the effect on the present value (and hence the apparent value of the costs) can be dramatic. Figure 1 shows the relationship between percent value and varying interest rates over time.

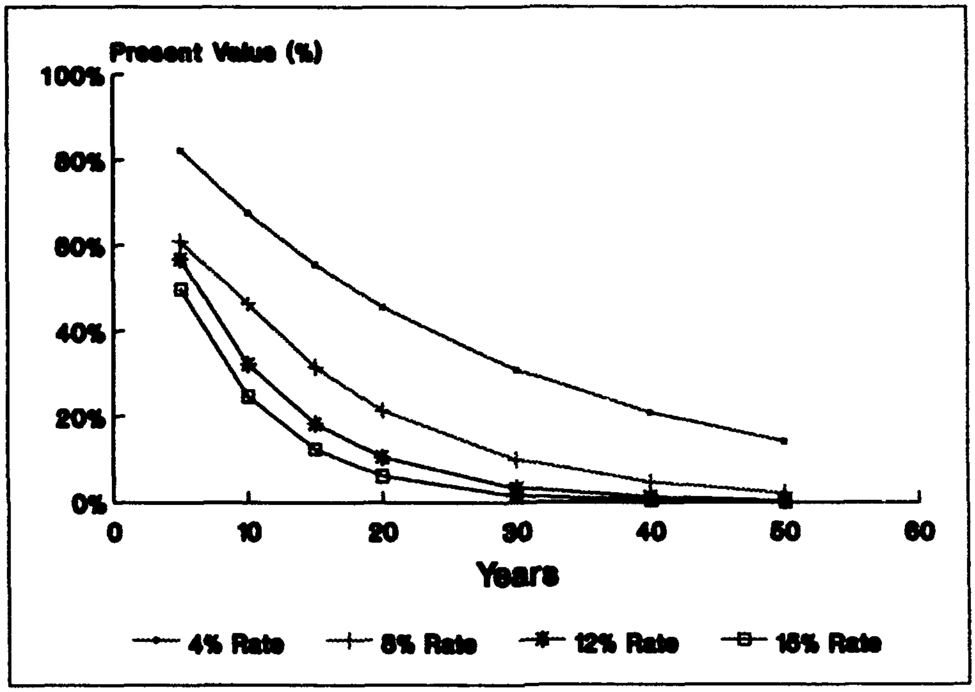

Figure 1. The Effect of Time on Present Value.

Most companies prefer a return on investment (ROI) or hurdle rate in the range of 10-15%; however, the Federal Government uses a 10% standard discount rate.

Appendix C

Expected Value Analysis

Appendix C

Expected Value Analysis

If probabilities are used to describe the occurrence of an event, expected value analysis can be used to determine the cost associated with such an event. For example, if the probability of a spill occurring is 60% (p=0.6) within the next year and the cost to clean-up an individual spill is $1000, then the annual expected cost of spills is $600 (0.6 x $1000). In other words, expected cost is the accumulated product of the probability of occurrence and the cost of each occurrence as illustrated in the following equation:

$$\textit{Expected Cost} = \Sigma(\textit{Probability of Occurrence} \times \textit{Cost of Each Occurrence})$$

Appendix D

Example Liability Factor Calculations

Appendix D

Example Liability Factor Calculations
(1:98-111)

The following computations for liability factors combine the risk factor, expected value, and present worth factors at the selected discount rate of 6% for landfill ages from 0 years (i.e., a new landfill) through 25 years. The formulas used for calculations in the following tables are:

Present Value Factor = PV Factor = $(1+r)^n$
r = discount rate = 6%
n = number of years until failure

Risk Factor = probability of failure in specified year at the given landfill age. For example, if the landfill was new, there would be a 2% chance of failure in 21 years, 14% in 22 years, 34% in 23 years, etc.

Expected Value = (present value factor) * (risk factor)

Liability Factor = sum of expected values

The resulting liability factor (f_L) for the given landfill ages, when multiplied by the cost of waste destruction, would represent the present value of the future destruction cost (i.e., the social cost of disposing of the waste in the landfill.)

		Landfill Age=0		Landfill Age=1	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0.02	0.006236
21	0.294155	0.02	0.005883	0.14	0.041181
22	0.277505	0.14	0.038850	0.34	0.094351
23	0.261797	0.34	0.089011	0.34	0.089011
24	0.246978	0.34	0.083972	0.14	0.034576
25	0.232998	0.14	0.032619	0.02	0.004659
26	0.219810	0.02	0.004396	0	0
	Liability Factor =		0.254733		0.270017

		Landfill Age=2		Landfill Age=3	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0.02	0.007006
19	0.330513	0.02	0.006610	0.14	0.046271
20	0.311804	0.14	0.043652	0.34	0.106013
21	0.294155	0.34	0.100012	0.34	0.100012
22	0.277505	0.34	0.094351	0.14	0.038850
23	0.261797	0.14	0.036651	0.02	0.005235
24	0.246978	0.02	0.004939	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.286218		0.303391

		Landfill Age=4		Landfill Age=5	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0.02	0.007872
17	0.371364	0.02	0.007427	0.14	0.051991
18	0.350343	0.14	0.049048	0.34	0.119116
19	0.330513	0.34	0.112374	0.34	0.112374
20	0.311804	0.34	0.106013	0.14	0.043652
21	0.294155	0.14	0.041181	0.02	0.005883
22	0.277505	0.02	0.005550	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.321595		0.340891

		Landfill Age=6		Landfill Age=7	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0.02	0.008846
15	0.417265	0.02	0.008345	0.14	0.058417
16	0.393646	0.14	0.055110	0.34	0.133839
17	0.371364	0.34	0.126263	0.34	0.126263
18	0.350343	0.34	0.119116	0.14	0.049048
19	0.330513	0.14	0.046271	0.02	0.006610
20	0.311804	0.02	0.006236	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.361344		0.383025

		Landfill Age=8		Landfill Age=9	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0.02	0.009939
13	0.468839	0.02	0.009376	0.14	0.065637
14	0.442300	0.14	0.061922	0.34	0.150382
15	0.417265	0.34	0.141870	0.34	0.141870
16	0.393646	0.34	0.133839	0.14	0.055110
17	0.371364	0.14	0.051991	0.02	0.007427
18	0.350343	0.02	0.007006	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.406006		0.430367

		Landfill Age=10		Landfill Age=11	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0.02	0.011167
11	0.526787	0.02	0.010535	0.14	0.073750
12	0.496969	0.14	0.069575	0.34	0.168969
13	0.468839	0.34	0.159405	0.34	0.159405
14	0.442300	0.34	0.150382	0.14	0.061922
15	0.417265	0.14	0.058417	0.02	0.008345
16	0.393646	0.02	0.007872	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.456189		0.483560

		Landfill Age=12		Landfill Age=13	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0.02	0.012548
9	0.591898	0.02	0.011837	0.14	0.082865
10	0.558394	0.14	0.078175	0.34	0.189854
11	0.526787	0.34	0.179107	0.34	0.179107
12	0.496969	0.34	0.168969	0.14	0.069575
13	0.468839	0.14	0.065637	0.02	0.009376
14	0.442300	0.02	0.008846	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.512574		0.543328

Year	PV Factor	Landfill Age=14 Risk Factor	Landfill Age=14 Expected Value	Landfill Age=15 Risk Factor	Landfill Age=15 Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0.02	0.014099
7	0.665057	0.02	0.013301	0.14	0.093107
8	0.627412	0.14	0.087837	0.34	0.213320
9	0.591898	0.34	0.201245	0.34	0.201245
10	0.558394	0.34	0.189854	0.14	0.078175
11	0.526787	0.14	0.073750	0.02	0.010535
12	0.496969	0.02	0.009939	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.575928		0.610483

		Landfill Age=16		Landfill Age=17	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0.02	0.015841
5	0.747258	0.02	0.014945	0.14	0.104616
6	0.704960	0.14	0.098694	0.34	0.239686
7	0.665057	0.34	0.226119	0.34	0.226119
8	0.627412	0.34	0.213320	0.14	0.087837
9	0.591898	0.14	0.082865	0.02	0.011837
10	0.558394	0.02	0.011167	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.647112		0.685939

		Landfill Age=18		Landfill Age=19	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0	0	0	0
2	0.889996	0	0	0.02	0.017799
3	0.839619	0.02	0.016792	0.14	0.117546
4	0.792093	0.14	0.110893	0.34	0.269311
5	0.747258	0.34	0.254067	0.34	0.254067
6	0.704960	0.34	0.239686	0.14	0.098694
7	0.665057	0.14	0.093107	0.02	0.013301
8	0.627412	0.02	0.012548	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.727096		0.770721

Year	PV Factor	Landfill Age=20 Risk Factor	Landfill Age=20 Expected Value	Landfill Age=21 Risk Factor	Landfill Age=21 Expected Value
1	0.943396	0.02	0.018867	0.16	0.150943
2	0.889996	0.14	0.124599	0.34	0.302598
3	0.839619	0.34	0.285470	0.34	0.285470
4	0.792093	0.34	0.269311	0.14	0.110893
5	0.747258	0.14	0.104616	0.02	0.014945
6	0.704960	0.02	0.014099	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.816965		0.864851

		Landfill Age=22		Landfill Age=23	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0.50	0.471698	0.84	0.792452
2	0.889996	0.34	0.302598	0.14	0.124599
3	0.839619	0.14	0.117546	0.02	0.016792
4	0.792093	0.02	0.015841	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.907685		0.933844

		Landfill Age=24		Landfill Age=25	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Expected Value
1	0.943396	0.98	0.924528	1.00	0.943396
2	0.889996	0.02	0.017799	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.942328		0.943396

Inflation Adjusted Liability Factors (1:112-114)

As before, the computations combine the risk factor, expected value, and present worth factors at the selected discount rate of 6% for landfill ages from 0 years (i.e., a new landfill) through 25 years, but they also include an inflation factor. The formulas used are:

Present Value Factor = PV Factor = $(1+r)^n$
r = discount rate = 6%
n = number of years to failure

Risk Factor = probability of failure in specified year at the given landfill age. For example, if the landfill was new, there would be a 2% chance of failure in 21 years, 14% in 22 years, 34% in 23 years, etc.

Inflation Factor = $(1 + i)^m$
i = inflation rate
m = number of years to failure

Expected Value = (present value factor) * (risk factor)

Liability Factor = sum of expected values

As before, the resulting liability factor (f_L) is multiplied by the cost of waste destruction to represent P_d - the inflation adjusted social cost of disposing of the waste in the landfill. The choice of the inflation rate is left up to the discretion of the user.

Example Calculations for a New Landfill (i.e., age = 0) with 3% Inflation

Year	PV Factor	Risk Factor	Inflation Factor	Expected Value
1	0.943396	0	1.03	0
2	0.889996	0	1.06	0
3	0.839619	0	1.09	0
4	0.792093	0	1.13	0
5	0.747258	0	1.16	0
6	0.704960	0	1.19	0
7	0.665057	0	1.23	0
8	0.627412	0	1.27	0
9	0.591898	0	1.31	0
10	0.558394	0	1.35	0
11	0.526787	0	1.39	0
12	0.496969	0	1.43	0
13	0.468839	0	1.47	0
14	0.442300	0	1.52	0
15	0.417265	0	1.56	0
16	0.393646	0	1.60	0
17	0.371364	0	1.65	0
18	0.350343	0	1.70	0
19	0.330513	0	1.75	0
20	0.311804	0	1.81	0
21	0.294155	0.02	1.86	0.01
22	0.277505	0.14	1.92	0.07
23	0.261797	0.34	1.97	0.18
24	0.246978	0.34	2.03	0.17
25	0.232998	0.14	2.09	0.07
26	0.219810	0.02	2.16	0.01
			Liability Factor =	0.51

Comparing this value, 0.51, to the initial liability factor (i.e., zero inflation), 0.255, can show the magnitude of the effects of inflation.

If similar calculations for all other age landfills and inflation rates of 0 - 7 percent were done, the results would be as follows:

Liability Factors for Landfills of Various Ages and 0% - 7% Inflation								
Age	0%	1%	2%	3%	4%	5%	6%	7%
0	.255	.322	.405	.510.	639	. 800	1.0	1.247
1	.270	.338	.421	.524.	652	.808	1.0	1.235
2	.286	.354	.438	.540	.664	.816	1.0	1.224
3	.303	.372	.455	.555	.690	.831	1.0	1.201
5	341	.410	.491	.588	.703	.839	1.0	1.190
6	.361	.430	.510	.605	.717	.847	1.0	1.179
7	.383	.451	.531	.623	.730	.855	1.0	1.168
8	.406	.473	.551	.641	.744	.863	1.0	1.157
9	.430	.497	.573	.660	.759	.872	1.0	1.146
10	.456	.521	.619	.699	.788	.888	1.0	1.125
12	.513	.574	.643	.719	.803	.897	1.0	1.114
13	.576	.633	.694	.762	.835	.914	1.0	1.093
15	.610	.664	.722	.784	.851	.923	1.0	1.083
16	.647	.697	.750	.807	. 867	.931	1.0	1.073
17	.686	.731	.779	.803	.884	.940	1.0	1.063
18	.727	.768	.810	.854	.901	.949	1.0	1.053
19	.771	.806	.842	.879	.918	.958	1.0	1.043
20	.817	.845	.875	.905	.936	.967	1.0	1.033
21	.865	.866	.908	.931	.953	.976	1.0	1.024
22	.908	.923	.938	.953	.969	.984	1.0	1.016
23	.934	.945	.956	.967	.978	.989	1.0	1.011
24	.942	.952	.962	.971	.981	.990	1.0	1.010
25	.943	.953	.962	.972	.981	.991	1.0	1.009

Appendix E

Case Study Calculations

Chemical: 10% Formalin

Cost Category: Procurement

Equation(s): $C_p = C_u * Q$

Variable	Value	Calculations	Source
C_u	$18	= ($72/case) * (case/4 Liters) = $18/Liter	9
Q	78 L	= Annual Quantity Used	9
C_p	**$1404**	= $18/Liter * 78 Liters = $1404	NA

Chemical: 10% Formalin

Cost Category: Transportation

Equation(s): $C_t = \Sigma C_e + \Sigma C_m$

Variable	Value	Calculations	Source
C_e	$988.65	= Annual cost to lease one truck w/hydraulic lift = ($2700/yr * 35.75%) + ($.195/mile * 120 miles/yr) = $965.25 + $23.40 = $988.65 (35.75% = percent of total HW)	6 22 44
C_e	$6.64	= Annual cost of fuel = 8 gals/yr * $0.83/gal = $6.64	44
C_m	$111.72	= Annual manpower cost = 6 manhours/yr * wage rate of 0-1* = 6 * $18.62/hr = $111.72	22
C_t	**$1107.01**	= Annual transportation cost = $988.65 + $6.64 + $111.72 = $1107.01	NA

* - see Appendix F for a complete listing of hourly wage rates:

Chemical: 10% Formalin

Cost Category: Personal Protective Costs

Equation(s): $C_{PPE} = \Sigma$ [NUMBER * C_{item} * PERIOD]

Variable	Value	Calculations	Source
NUMBER	2 Tyveks/yr	On one sampling day two people sampled all three waste streams using 1 Tyvek each.	10
C_{item}	\$3.60/Tyvek	2 * \$3.60 = \$7.20	50
PERIOD	1 yr	This was supposed to be the only sample required for the whole year.	10
NUMBER	2 Tyveks/yr	2 people sampled 10% Formalin again due to disposal questions. They each wore one Tyvek each.	10
C_{item}	\$3.60/Tyvek	2 * \$3.60 = \$7.20	50
PERIOD	1 yr	This was an additional sample period in the same year.	10
NUMBER	.8 Tyveks/yr	2 people responded in double Tyveks once every five years (see Emergency response--expected value = .2) 2 people/spill * 2 Tyvek/person * .2 spill/year	10
C_{item}	\$3.60/Tyvek		50
PERIOD	1 yr		10
C_{PPE}	**\$17.28**	2 Tyveks/yr * \$3.60/Tyvek * 1 yr + 2 Tyveks/yr * \$3.60/Tyvek * 1 yr + .8 Tyveks/yr * \$3.60/Tyvek * 1 yr = \$17.28	NA

Normalin (the replacement chemical) is non-hazardous and therefore has no projected PPE costs.

Chemical: 10% Formalin

Cost Category: Monitoring--Spills

Equation(s):

$$C_{ms} = \Sigma C_{probable} = \Sigma(E_{sp} * E_{sa} * C_{sa})$$

$$C_{sa} = \text{analysis} + \text{supplies}$$

Variable	Value	Calculations	Source
E_{sp}	.2 Spills/ yr	1 spill of formaldehyde in last five years. See Emergency response--Expected value = .2 spills/yr)	10
E_{sa}	2 Samples /spill	Obtained by professional knowledge of average samples/spill	10
analysis	$0.00	Direct reading tubes are used for spills; therefore, there are no costs for analysis.	10
supplies	$2.50/ sample tube	Direct reading tubes for formaldehyde cost $2.50 each.	10
C_{sa}	$2.50/ sample	$0.00 + $2.50 = $2.50	NA
C_{ms}	$1	.2 spills/yr *2 samples/spill * $2.50/sample = $1/yr Therefore, the annual cost is $1.	NA

Normalin (the replacement chemical) is non-hazardous and, therefore, has no projected Spill monitoring costs

Chemical: 10% Formalin

Cost Category: Monitoring--Waste

Equation(s):

$$C_{mw} = \Sigma C_{known}$$

$$C_{known} = (\text{WAGES} * \text{HOURS} * \text{NUMBER}) + (\text{SAMPLES} * C_{unit})$$

Variable	Value	Calculations	Source
WAGES	$10.84/hr	Two personnel were used to take the sample (a SrA and an A1C) [$11.26/hr (SrA) + $10.43/hr (A1C)] / 2 =$10.84/hr	10
HOURS	3hr/ person	1.5 hours per person per sample time with two sample times per year. (1.5hr/person/time) * 2 times = 3 hr/person	10
NUMBER	2 people	Two personnel are always used to take a hazardous waste sample.	10
SAMPLES	3 samples	In 1992, there was a requirement to test the waste stream 3 times.	8
consumable	$23.56/ sample	coliwasa ($88.50 for 12) = $7.38/sample 4 Tyvek used per sample($3.60 ea) = $14.40/sample 1 bottle per sample ($32 for 18) = $1.78/sample ($7.38 + $14.40 + $1.78)/sample = $23.56/sample	10
analysis	$431.50/ sample	According to AL/OEAT the contract price for analysis is: $8-20 for pH, $30-55 for ignitability, $60-95 reactivity, $225-370 for major components. The average of the median costs are $431.50/sample	52
C_{unit}	$455.06/ sample	$23.56/sample + $431.50/sample = $455.06/sample	NA
C_{known}	$1430.22	3 samples * $455.06/sample + ($10.84/hr * 3 hr/person * 2 people) = $1430.22	NA
C_{mw}	$1430.22	In this case there is only one chemical analysis being performed so $C_{known} = C_{mw}$	NA

Normalin (the replacement chemical) is non-hazardous and, therefore, has no projected waste monitoring costs.

Chemical: 10% Formalin

Cost Category: Monitoring--Health

Equation(s):

$$C_{health} = \Sigma[(\text{PERSONAL} + \text{AREA}) * C_{unit}] + \text{WAGES} * \text{HOURS} * \text{NUMBER}$$

$$C_{unit} = \text{supplies} + \text{analysis}$$

Variable	Value	Calculations	Source
PERSONAL	4 samples /yr	Four personal monitoring samples were collected during the last Industrial Hygiene Survey.	8
AREA	4 samples /yr	Four area monitoring samples were collected during the last Industrial Hygiene Survey.	8
supplies	$22.74/ dosi-meter	A box of five dosimeters cost $113.70 $113.70 / 5 dosimeters = $22.74/dosimeter	7
analysis	$60/ dosi-meter	According to the Occupational and Environmental Health Lab (AL/OEAO), the contract price to have a dosimeter analyzed is $60.	39
WAGES	$13.28/ hour	[$18.97/hr (TSgt) + 2 * $10.43/hr (A1C)] / 3 = $13.28/hr	10
HOURS	4 hr/man	Each person put in four hours into performing the sampling.	10
NUMBER	3 people	There were three people required to perform the sampling (1 TSgt and 2 A1Cs).	10
C_{unit}	$82.74/ dosi-meter	C_{unit} = supplies + analysis = $22.74/dosimeter + $60/dosimeter = $82.74/dosimeter	NA
C_{health}	$826.50	Σ[(PERSONAL + AREA) * C_{unit}] + WAGES * HOURS * NUMBER = [(4 samples/yr + 4 samples/yr) * $82.74/dosimeter] + $13.28/hr * 4 hr/yr * 3 people = $826.50 for one year	NA

Chemical: 10% Formalin

Cost Category: Monitoring--Total Costs

Equation(s):

$$C_{monitor} = \Sigma C_{spill/waste} + \Sigma C_{health} + \Sigma C_{permits}$$

$$C_{spill/waste} = C_{mw} + C_{ms}$$

Variable	Value	Calculations	Source
C_{mw}	\$1430.22	See the worksheet "Monitoring-Waste"	NA
C_{ms}	\$1	See the worksheet "Monitoring-Spills"	NA
$C_{spill/waste}$	\$1431.22	\$1430.22 + \$1 = \$1431.22	NA
C_{health}	\$826.50	See the worksheet "Monitoring-Health"	NA
$C_{permits}$	\$0.00	There are no permits on base with regards to formaldehyde.	50
$\mathbf{C_{monitor}}$	**\$2257.72**	$C_{spill/waste} + C_{health} + C_{permits}$ \$1431.22 + 826.50 + \$0.00 = \$2257.72	NA

Chemical: 10% Formalin

Cost Category: Medical Costs--Physical Exams

Equation(s):

$$C_{pe} = (EXAMS_d * DOCWAGES * TIME_{appt}) + (EXAMS_n * NURSEWAGES * TIME_{appt}) + (EXAMS_m * SUMWAGES * TIME_{appt})$$

Variable	Value	Calculations	Source
$EXAMS_d$	10 people/ year	Each of the people within the shop have been determined to need the physical exams each year due only on the basis of the formaldehyde use.	23
DOCWAGES	$32.06/ hr	The only physician that performs these physicals is Capt. Grise, the flight surgeon.	23
$TIME_{appt}$	1/3 hr/ person	Each physical takes 1/3 hour with the doctor.	23
$EXAMS_n$	0	There are no nurses that are assigned to the Flight Medicine area of the clinic.	23
NURSEWAGES	NA		NA
$EXAMS_m$	10 people/ yr	same as $EXAMS_d$	30
SUMWAGES	$1.26/ hr	The support personnel for the physicals consists primarily of a single SrA with an hourly wage rate of $11.26/hr.	23
$TIME_{appt}$	1/3 hr/ person	Each exam takes 1/3 hour with the support personnel (see SUMWAGES).	23
C_{pe}	$144.50	[10 people/yr * $32.06/hr * (1/3 hr/person)] + [10 people/yr * $11.26/hr * (1/3 hr/person)] = $144.40 per year.	NA

Chemical: 10% Formalin

Cost Category: Medical Costs--Administrative

Equation(s):

$$C_{admin} = HOURS * APPT * WAGES$$

Variable	Value	Calculations	Source
HOURS	1/12 hr/ person	Each appointment takes about five minutes to schedule and then have the medical records delivered to the patient.	54
APPT	10 people	All ten people within the organization receives a medical appointment due solely on the use of formaldehyde.	23
WAGES	$13.51/ hr	The administration functions are usually handled by a Sgt with an hourly wage of $13.51.	54
C_{admin}	$11.26	1/12 hr/person * 10 people * $13.51/hr = $11.26	NA

Chemical: 10% Formalin

Cost Category: Medical Costs--Surveillance (laboratory)

Equation(s):

$$C_{surv} = \Sigma(C_{man} + C_{testing})$$

$$C_{man} = E_{referrals} * WAGES * HOURS$$

$$C_{testing} = E_{referrals} * E_{tests} * C_{test}$$

Variable	Value	Calculations	Source
$E_{referrals}$	10 people	Each person received a CBC with Differential last year. This next year no physicals will be given and, therefore, no CBC with differentials will be done. This reduced cost is not completely due to the formaldehyde removal.	30
WAGES	$16.08/ hr	These tests are performed by an E-5 earning $16.08/hr.	14
HOURS	1/3 hr/ test	Each CBC with differential takes about 20 minutes to perform.	14
C_{man}	$53.60	10 people * $16.08/hr * 1/3 hr/person = $53.60	NA
E_{tests}	1 tests /person	One test per person is needed.	23
C_{test}	1$/test	This is the cost of the test package. The cost of the hardware is not included because it would be required regardless if the change in hazardous materials is implemented.	14
$C_{testing}$	$10	10 people * 1 test/person * $1/test = $10	NA
C_{surv}	$63.60	$\Sigma(C_{man} + C_{testing}) = C_{surv}$ $53.60 + $10 = $63.60	NA

Chemical: 10% Formalin

Cost Category: Medical Costs--BEE Shop

Equation(s):

$$C_{BEE} = \Sigma \text{ (WAGES * HOURS)}$$

Variable	Value	Calculations	Source
WAGES	$29.40/ hr	This survey was performed by one TSgt and 1 A1C. $18.97/hr (TSgt) + $10.43/hr (A1C) = $29.40/hr	10
HOURS	4 hrs	Both the TSgt and the A1C put 24 hours into the annual survey for this area last year. Four hours was estimated to be due solely to the use of formaldehyde such as chemical research and extra ventilation surveys.	10
C_{BEE}	$117.60	Σ (WAGES * HOURS) = C_{BEE} $29.40/hr * 4 hr = $117.60	NA

Chemical: 10% Formalin

Cost Category: Medical Costs--Lost time from Physicals

Equation(s):

$$C_{LT} = WAGES * (APPT + OTHER) * NUMBER$$

Variable	Value	Calculations	Source
WAGES	$22.76/ person	The average wage of all 10 of the personnel within the Anatomic pathology laboratory (see Emergency Response's variable ORGRATE).	30
APPT	1 hr	From the Medical Costs--Physical exams and --laboratory the appointment takes 20 min for preexams, 20 min with the doctor, and 20 min at the lab. 20 min + 20 min + 20 min = 1 hr	23
OTHER	.5 hr	The expected travel time and waiting time has been estimated to be .5 hrs	23
NUMBER	10 people	There are 10 people within the Anatomic Pathology lab that receive physicals due to the use of 10% formalin.	30
C_{LT}	$341.40	WAGES * (APPT + OTHER) * NUMBER = C_{LT} $22.76/person * (1 hr + .5 hr) * 10 people = $341.40	NA

Chemical: 10% Formalin

Cost Category: Medical Costs--Total Costs

Equation(s):

$$C_{medical} = \Sigma C_{pe} + \Sigma C_{admin} + \Sigma C_{surv} \Sigma C_{BEE} + \Sigma C_{LT}$$

Variable	Value	Calculations	Source
C_{pe}	$144.50	See the worksheet "Medical--Physical Exams"	NA
C_{admin}	$11.26	See the worksheet "Medical--Administrative"	NA
C_{surv}	$63.60	See the worksheet "Medical--Surveillance"	NA
C_{BEE}	$117.60	See the worksheet "Medical--BEE Shop"	NA
C_{LT}	$341.40	See the worksheet "Medical--Lost Time from Physicals""	NA
$C_{medical}$	**$678.36**	$\Sigma C_{pe} + \Sigma C_{admin} + \Sigma C_{surv} \Sigma C_{BEE} + \Sigma C_{LT} = C_{medical}$ $144.50 + $11.26 + $63.60 + $117.60 + $341.40 = $678.36	NA

Chemical: 10% Formalin

Cost Category: Emergency Response Cost

Equation(s): $C_{er} = [\Sigma C_e + \Sigma C_m] * E_{er}$

$$C_m = RATE * HOURS_1 * Number_1 + ORGRATE * HOURS_2 * NUMBER_2$$

Variable	Value	Calculations	Source
ΣC_e	$0.00	No equipment is required that would not still have been required if the spill had not occurred.	10
RATE	$20.49 /hr	[$32.06/hr (Capt) + $18.97/hr (TSgt) + $10.43/hr (A1C)] /3 = $20.49/hr	10
$HOURS_1$	3 hr /person		10
$Number_1$	3 people		10
ORGRATE	$22.76 /hr	There are ten people in the shop that would be displaced during a spill. [2 * $11.26/hr (SrA) + 2 * $13.51/hr (Sgt) + 2 * $16.08/hr (SSgt) + $18.97/hr (TSgt) + 2 * $40.09/hr (Maj) + $46.72/hr (Lt Col)] / 10 = $22.76/hr	30
$HOURS_2$	3 hr /person		10
$NUMBER_2$	10 people		30
ΣC_m	$867.21	$20.49/hr * 3 hr/person * 3 people + $22.76/hr * 3 hr/person * 10 people = $867.21	NA
E_{er}	.2 spills/ yr	There has been one reported incident of a formaldehyde spill in the last five years. The prediction for the next five years then is also one spill. Therefore 1 spill / 5 years = .2 spill/yr	8
C_{er}	**$173.44**	[$0.00 + $867.21] * .2 = 173.44	NA

Normalin (the replacement chemical) is non-hazardous and, therefore, has no projected emergency response costs.

Chemical: 10% Formalin

Cost Category: Disposal

Equation(s): $C_d = \Sigma C_m + \Sigma C_s + \Sigma C_{td}$

$C_m = \Sigma(\text{RATE} * \text{MANHOURS})$

$C_s = \Sigma(\text{annual supply costs})$

$C_{td} = C_u * \text{UNITS}$

Variable	Value	Calculations	Source
C_m	$6739.88	Annual manpower cost = (238 manhours/yr * wage rate of 0-1) + (72 manhours/yr * wage rate of 0-3) = (238 * $18.62/hr) + (72 * $32.06/hr) = $6739.88	22
C_s	$50.00	Annual cost of supplies such as labels, markers, containers, etc.	22
C_{td}	$14,882.33	C_u = $1.81/lb UNITS = 310.8 Kg/month = 8222.28 lbs/yr $C_{td} = C_u$ * UNITS = $1.81/lb * 8222.28 lbs = $14,882.33	22
C_d	**$21,672.21**	$C_d = \Sigma C_m + \Sigma C_s + \Sigma C_{td}$ = $6739.88 + $50.00 + $14,882.33 = $21,672.21	NA

Chemical: 10% Formalin

Cost Category: Liability

Equation(s): $C_L = C_{tt} + C_{rpd} + C_{nrd} + C_{fp} + C_{pf} + C_{rc} + C_{lhw}$

$C_{tt} = 1.12 * Q$

$C_{rpd} = 4.8 \times 10^{-6} * Q * VALUE$

$C_{nrd} = 4.83 * Q$

$C_{rc} = \Sigma(MANHOURS * RATE)$

Variable	Value	Calculations	Source
C_{tt}	$9,208.95	= 1.12 * Q = 1.12 * 8222.28lbs = $9,208.95	22
C_{rpd}	$773.63	= 4.8 x 10^{-6} * Q * VALUE = 4.8 x 10^{-6} * 8222.28 * $19,602 = $773.63	22 5
C_{nrd}	$39,713.61	= 4.83 * Q = 4.83 * 8222.28lbs = $39,713.61	22
C_{fp}	NA	Based on historical data, the probability of receiving a fine/penalty is zero.	22
C_{pf}	NA	No permitting fees	22
C_{rc}	$1,202.70	= MANHOURS * RATE = 30 hrs * wage rate of 0-4 = 30 * $40.09/hr = $1202.70	43
C_{lhw}	NA	Hazardous waste is not landfilled.	22
C_L	**$50,898.89**	= $9208.95 + $773.63 + 39,713.61 +1202.70 = $50,898.89	NA

Chemical: Normalin®

Cost Category: Procurement

Equation(s): $C_p = C_u * Q$

Variable	Value	Calculations	Source
C_u	$17	= $85/5 gals = $17/gal	46
Q	17.158 gals	= Annual Quantity Used = 78 L * (1 gal/4.546 L) = 17.158 gals	9
C_p	**$291.69**	= $17/gal * 17.158 gals = $291.69	NA

Chemical: Clearing Agents (xylene & Histoclear®)

Cost Category: Procurement

Equation(s): $C_p = \Sigma(C_u * Q)$

Variable	Value	Calculations	Source
C_u	$13.52	= Unit Cost of Xylene = $13.52/gal	9
Q	39 gals	= Annual Quantity of Xylene Used	9
C_u	$17.10	= Unit Cost of Histoclear® = $17.10/gal	9
Q	52 gals	= Annual Quantity of Histoclear® Used	9
C_p	**$1,416.48**	= ($13.52 * 39) + ($17.10 * 52) = $527.28 + $889.20 = $1,416.48	NA

Chemical: Clearing Agents (xylene & Histoclear®)

Cost Category: Transportation

Equation(s): $C_t = \Sigma C_e + \Sigma C_m$

Variable	Value	Calculations	Source
C_e	$221.85	= Annual cost to lease one truck w/hydraulic lift = ($2700/yr * 7.35%) + ($.195/mile * 120 miles/yr) = $198.45 + $23.40 = $221.85 (7.35% = percent of total HW)	6 22 44
C_e	$6.64	= Annual cost of fuel = 8 gals/yr * $.83/gal = $6.64	44
C_m	$111.72	= Annual manpower cost = 6 manhours/yr * wage rate of 0-1 = 6 * $18.62/hr = $111.72	22
C_t	**$340.21**	= Annual transportation cost = $221.85 + $6.64 + $111.72 = $340.21	NA

Chemical: Clearing Agents (xylene & Histoclear®)

Cost Category: Disposal

Equation(s): $C_d = \Sigma C_m + \Sigma C_s + \Sigma C_{td}$

$C_m = \Sigma(\text{RATE} * \text{MANHOURS})$

$C_s = \Sigma(\text{annual supply costs})$

$C_{td} = C_u * \text{UNITS}$

Variable	Value	Calculations	Source
C_m	\$1,638.56	Annual manpower cost = (88 manhours/yr * wage rate of 0-1) = 88 * \$18.62/hr = \$1,638.56	22
C_s	\$50.00	Annual cost of supplies such as labels, markers, containers, etc.	22
C_{td}	\$3,059.78	C_u = \$1.81/lb UNITS = 63.90 Kg/month = 1,690.49 lbs/yr $C_{td} = C_u$ * UNITS = \$1.81/lb * 1690.49 lbs = \$3,059.78	22
C_d	**\$4,748.34**	$C_d = \Sigma C_m + \Sigma C_s + \Sigma C_{td}$ = \$1.638.56 + \$50.00 + \$3,059.78 = \$4,748.34	NA

Chemical: Clearing Agents (xylene & Histoclear®)

Cost Category: Liability

Equation(s): $C_L = C_{tt} + C_{rpd} + C_{nrd} + C_{fp} + C_{pf} + C_{rc} + C_{lhw}$

$$C_{tt} = 1.12 * Q$$

$$C_{rpd} = 4.8 \times 10^{-6} * Q * VALUE$$

$$C_{nrd} = 4.83 * Q$$

$$C_{rc} = \Sigma(MANHOURS * RATE)$$

Variable	Value	Calculations	Source
C_{tt}	\$1,893.35	= 1.12 * Q = 1.12 * 1,690.49 lbs = \$1,893.35	22
C_{rpd}	\$159.06	= 4.8×10^{-6} * Q * VALUE = 4.8×10^{-6} * 1,690.49 * \$19,602 = \$159.06	5 22
C_{nrd}	\$8,165.07	= 4.83 * Q = 4.83 * 1,690.49lbs = \$8,165.07	22
C_{fp}	NA	Based on historical data, the probability of receiving a fine/penalty is zero.	22
C_{pf}	NA	No permitting fees	22
C_{rc}	NA	No regulatory correspondence cost	43
C_{lhw}	NA	Hazardous waste is not landfilled.	22
C_L	**\$10,217.48**	= \$1,893.35 + \$159.06 + \$8,165.07 = \$10,217.48	NA

Chemical: Slide-Brite®

Cost Category: Procurement

Equation(s): $C_p = C_u * Q$

Variable	Value	Calculations	Source
C_u	$15	= $60/4 gals = $15/gal	46
Q	91 gals	= Annual Quantity Used = 78 L * (1 gal/4.546 L) = 17.158 gals	9
C_p	**$1,365**	= $15/gal * 91 gals = $1365.00	NA

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Appendix F

Hourly Wage Rates

Appendix F

Hourly Wage Rates (FY92$)
(3:C-4)

Grade	Hourly Rate
Officer 0-6	$55.02
Officer 0-5	$46.72
Officer 0-4	$40.09
Officer 0-3	$32.06
Officer 0-2	$24.01
Officer 0-1	$18.62
Enlisted E-9	$30.30
Enlisted E-8	$25.61
Enlisted E-7	$22.08
Enlisted E-6	$18.97
Enlisted E-5	$16.08
Enlisted E-4	$13.51
Enlisted E-3	$11.26
Enlisted E-2	$10.43
Enlisted E-1	$8.75

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Vita

Captain Blaine F. Burley was born on 20 February 1966 in Atlanta, Georgia. In 1984, he graduated from Irwin County High School in Ocilla, Georgia. He then attended the U.S. Air Force Academy Preparatory School where he graduated as an honor graduate in 1985. In 1989, he graduated from the U.S. Air Force Academy where he received a Bachelor of Science Degree in Civil Engineering (Environmental Tract). From May 1990 to May 1992, he was assigned to Myrtle Beach AFB, S.C., as an Environmental Engineer where he managed the handling and disposal of all hazardous and toxic waste generated on base. He is currently attending the Air Force Institute of Technology as a graduate student in the Engineering and Environmental Management Program.

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Vita

Captain Kirk A. Phillips was born on 24 November 1966 in Aurora, Colorado. In 1985, he graduated from Glendale High School in Springfield, Missouri. He then attended the University of Missouri at Rolla where he graduated in 1989 with a Bachelor of Science Degree in Aerospace Engineering. From January 1990 to May 1990, he attended the School of Aerospace Medicine, Brooks AFB, TX, Bioenvironmental Engineering Course. Upon graduation he was assigned to Brooks AFB, TX, as the Base Bioenvironmental Engineer where he managed the Brooks AFB Bioenvironmental Engineering Office. He is currently attending the Air Force Institute of Technology as a graduate student in the Engineering and Environmental Management Program.

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13. ABSTRACT (Maximum 200 words)
This research focuses on the development of a decision support model to select cost-effective alternatives for hazardous materials using life cycle cost (LCC) analysis. The model provides an effective decision-making tool to evaluate the economic feasibility of using alternatives for hazardous materials.

Given a specific operation, the users of this model can enter site-specific cost data to determine the total LCCs of using baseline hazardous materials (i.e., hazardous materials currently being used in an operation), as well as the total LCCs of using various alternatives. This thesis postulates that the material having the lowest total LCC is considered to be the "best" alternative. In calculating the total LCC of a material, the following 12 LCC categories are evaluated: procurement, transportation, handling, facility, personal protection, medical, training, emergency response, monitoring, disposal, liability, and intangible cost.

This research also includes a case study of an Air Force operation (Pathology Lab Tissue Processing) to illustrate the use of the decision support model. Although the case study specifically addresses a single Air Force operation, the model can be applied to any operation that uses hazardous materials.

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